Plug-in hybrids: Is Europe heading for a new dieselgate?

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Published: November 2020
In-house analysis by Transport & Environment, testing of cars undertaken by Emissions Analytics on behalf of Transport Environment.

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To cite this study

Transport & Environment (2020). *A new Dieselgate in the making.*

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Acknowledgements

The authors kindly acknowledge the external peer reviewers Peter Mock and Georg Bieker from the International Council on Clean Transportation and Julius Jöhrens from the Institute for Energy and Environmental Research, Heidelberg. Particular thanks goes to Patrick Plötz from the Fraunhofer Institute for providing the real world utility factors used in this report. The findings and views put forward in this publication are the sole responsibility of the authors listed above. The same applies to any potential factual errors or methodology flaws.

Executive Summary

Plug-in hybrid vehicle (PHEV) sales are skyrocketing in Europe with half a million expected to be sold this year alone. Carmakers need to sell low emission vehicles to comply with the 2020/21 EU car CO2 standard which took effect in January 2020. But are these cars as low emission in the real world as in carmaker test labs? Or are PHEVs high emitting vehicles that carmakers sell as a compliance trick to meet the CO2 targets? To find out, Transport & Environment has commissioned Emissions Analytics to test three of the most popular PHEVs sold in 2019: a **BMW X5** (longest EV range PHEV available), a **Volvo XC60** and the **Mitsubishi Outlander.** This report presents the test results and what they mean for the CO2 credentials of this technology.

Even in optimal test conditions PHEV emissions are 28-89% higher than advertised

Many PHEVs on sale today tout very low CO2 emissions - a third, or less of an equivalent conventional combustion engined car. However, none of the PHEVs tested achieve such low figures in the real world even when tested on the mildest of the tests and starting with a fully charged battery. Of the three PHEVs tested by T&E the best performer on this test was the BMW X5, but it still exceeded official CO2 values by 28%, emitting 41g/km. On the same mild test, the XC60 and Outlander emitted 115g/km and 86g/km respectively, a gap of 62%- 89% compared with official WLTP values.

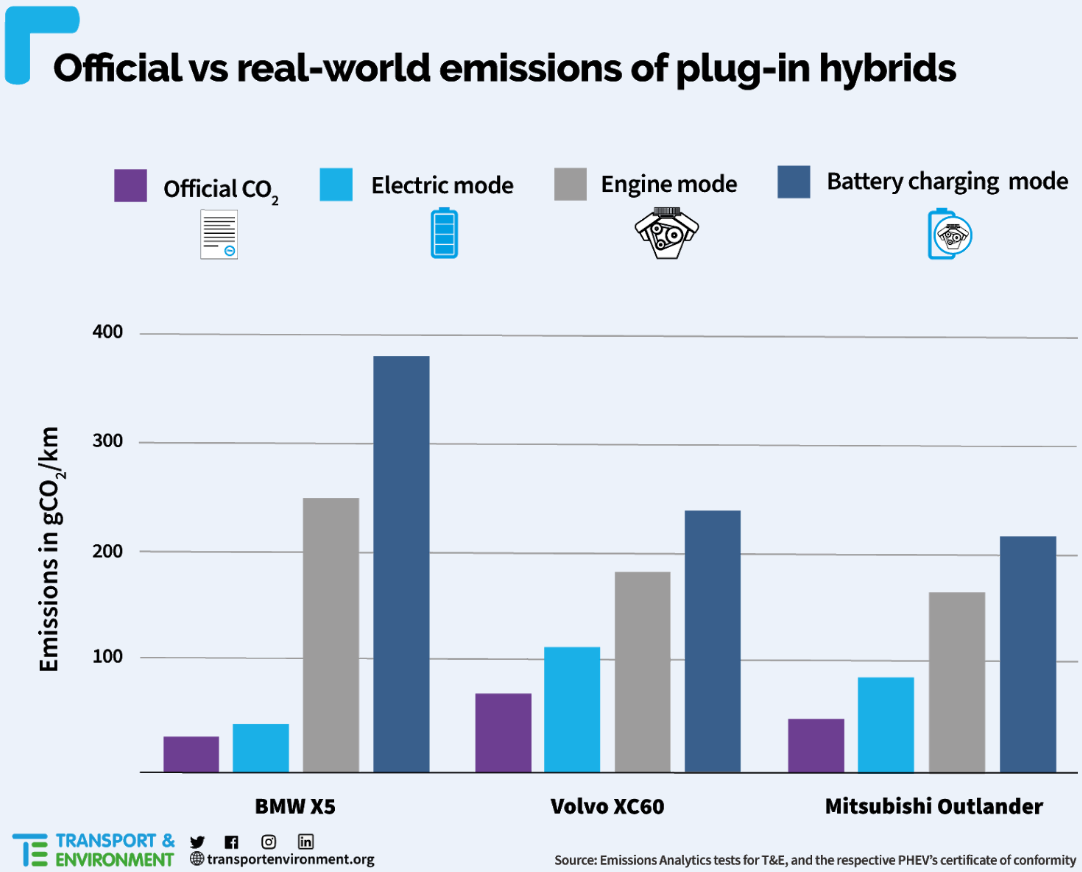

Figure 01: CO2 emissions of the tested plug-in hybrids as measured on T&E's tests.

In engine mode PHEVs emit up to 8 times more than advertised

On tests where the car started with an empty battery (i.e. the internal combustion engine was powering the car) CO2 emissions of the XC60 and the Outlander surged up to 184g/km and 164g/km respectively, or almost 3-4 times higher than official values. The CO2 emissions of the X5 increased even more, up to 254g/km , or eight times higher than official values.

Geo-fencing could increase PHEV emissions by 12 times
The worse results were observed in tests where the engine was also used to charge the battery, a mode of operation that is likely to increase if geo-fencing technology is used in the future and drivers need to charge their batteries before entering a zero emission zone in a city. The X5 CO2 emissions in this mode exceed the official CO2 values by 12 times; for the XC60 and the Outlander - by 3.4 and 4.7 times respectively. For the X5 and the Outlander the additional CO2 emitted to charge the battery alone exceeded the cars' official CO2 emissions.

Some PHEVs are not designed for dynamic electric driving
As soon as the three PHEVs are tested with faster accelerations, higher payload or in motorway driving, the electric-only range drops by up to 76%, depending on car and test. The X5 and XC60 in particular failed to stay in EV-only operation under fast acceleration. On one test the engine came on after as little as 18km for the X5 and 11km for the XC60 - reducing the EV-only range by three quarters - despite the battery being fully charged. This shows that, for these two cars, the **electric drive is not capable of providing the necessary power** resulting in the combustion engine coming on sooner. This demonstrates that some PHEVs are only designed to stay in zero emission operation under a narrow range of on-road driving conditions, and that the CO2 emitting engine can be used frequently in everyday driving.

T&E estimates that once the three vehicles switch into engine (ICE) mode, they can only drive 11km, 23km and 19km respectively for the X5, XC60 and Outlander before they overshoot their official CO2 limits. This means that in total they can only be driven between 61-86km before exceeding their official emissions, with longer journeys resulting in high CO2. For example, a 100km trip on one charge - e.g. driving from Brussels to Bruges - would result in estimated CO2 emissions of 64g/km for the X5, 116g/km for the XC60 and 87g/km for the Outlander, up to 2 times the official value. This in effect **turns around the misleading narrative around PHEVs being good for longer journeys**: PHEVs on sale today are only suited for short journeys where most of the km's driven are electric. They have to be charged much more frequently than battery electric cars (which do around 300km on one charge) if they are to keep their low emission vehicle label.

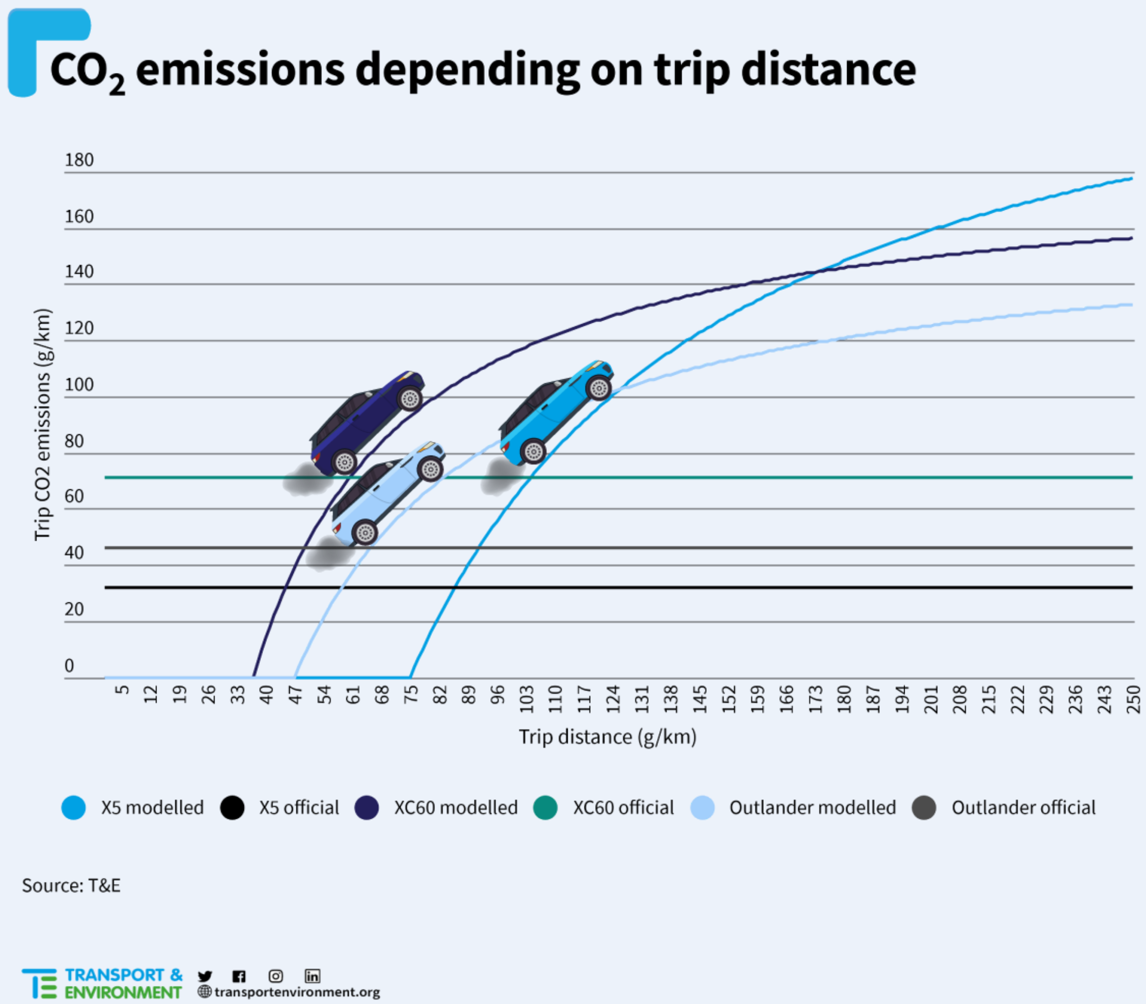

Figure 02: Modelled trip CO2 emissions, depending on trip distance when starting in EV-only driving with a full battery.

It is not all drivers' fault: current PHEVs are not designed to be used in zero emission mode

For PHEVs to be part of the transition to zero emission mobility they have to deliver the claimed CO2 and fuel savings on the road, i.e. drive predominantly in zero emission mode in all on-road conditions. But the PHEV models on sale today do not make it easy. For example, many/most PHEVs cannot fast charge - in our case only the Outlander had that capability. Even the BMW's

X5 which has a large 24kWh battery cannot be topped up quickly on the go; slow charging would take up to 7 hours. Other examples include the Outlander manual that states that the engine may start if the PHEV system is too hot/too cold, quick acceleration is applied or the air conditioning is operating.

The three PHEVs' realistic CO2 emissions

In most cases PHEVs have CO2 official test values of less than 50g/km, the threshold needed to access generous super credits in the car CO2 regulation (or zero and low emission vehicle credits from 2025) and various tax advantages. This is predominantly caused by the regulation using overly optimistic assumptions on the share of electric kilometers driven by PHEVs - known as 'utility factors' - compared to the actual share of electric kilometers in the real world. This results in unrealistically low CO2 values for PHEVs, whose average use in the real world does not deliver these CO2 savings.

T&E used real world PHEV usage data - or utility factors - from Germany to calculate more realistic official CO2 emissions for the three tested PHEVs (based on NEDC). The analysis shows that PHEV emissions should be between 50-230% higher than what is claimed today. For private drivers the NEDC CO2 emissions should be 60g/km for the X5, 87g/km for the XC60 and 64g/km for the Outlander, compared to just 41g/km (X5), 55g/km (XC60) and 40g/km (Outlander) officially. For company car users the emissions are even higher: 137g/km for the X5, 125g/km for the XC60 and 102g/km for the Outlander, due to even less EV driving. Data from Germany, the Netherlands and Belgium shows that company PHEVs drive between 76%-92% of total annual kilometers using the combustion engine.

Compliance with EU CO2 standards

Compliance with the 2020 car CO2 targets would also be impacted if more realistic PHEV CO2 emissions were used. In the case of BMW and Volvo - which are over-complying on the current forecast - if average German private and company utility factors were applied EU-wide the fleet-wide CO2 emissions would be 8-11g/km higher for BMW, and 8-14g/km higher for Volvo, making both non-compliant. To achieve their current fleet-wide CO2, BMW's and Volvo's PHEVs would have to drive close to 70% of total kilometers electrically, far more than current real-world usage shows. As such, manufacturer's are using PHEVs as a compliance strategy to easily meet their CO2 targets without the cars actually achieving these savings in the real world. **It is highly unlikely that either carmaker would meet their CO2 targets (or earn as**

many super credits) with their current PHEV sales if more representative CO2 values for those were used.

PHEVs unfairly benefit from huge subsidies

High CO2 emissions of PHEVs in the real-world also mean the tax support for them is not justified. T&E commissioned Schmidt Automotive Research to calculate how much public money will go into subsidising private and corporate PHEV sales in 2020. It turns out Germany, France, Italy, Spain and the UK are due to spend EUR 1bln this year subsidising PHEVs with limited real-world CO2 benefit. EUR 555 million alone is expected to be lost in foregone tax revenue due to lower rates of benefit in kind tax applied to company PHEVs, and over EUR 436 million in private purchase support until September. This makes PHEVs not just a CO2 compliance trick, but also a tax loophole.

Recommendations

If car manufacturers want PHEVs to be part of the transition to zero emission mobility they have to improve their real world performance. This means increasing their real world electric range to at least 80km, ensuring that they can stay in electric mode under a wide range of driving conditions without using the combustion engine, significantly reducing the CO2 emissions when the engine is running and fitting fast charging.

Policy-makers should:

1. End purchase subsidies for private or company car PHEVs - only zero emission vehicles should be eligible for purchase subsidies.
2. Ensure that only PHEVs with an electric range of more than 80km, sufficient power to use zero emission mode, low engine-only emissions and fast charging are eligible for various tax support such as CO2-based registration taxes. Access to charging at home or work must be a condition for getting public subsidies.
3. Using data from on-board fuel consumption meters, use more representative PHEVs CO2 emission values for compliance with the EU CO2 emission targets and for type-approval. OBFCM data should be used to determine realistic utility factors for PHEVs per manufacturer. OEM-level data is not sufficient.

4. Remove the 0.7 multiplier from the Zero and Low Emission Vehicle (ZLEV) credits as part of the 2021 review of car CO2 emission standards to make it harder for suboptimal compliance PHEVs to earn credits.
5. Improve the WLTP test procedure used to determine PHEV type approval emissions, notably by including the use of auxiliaries, updating the definition of electric range and removing the current corrections.

Fundamentally, it is simply not enough to fit an electric motor and a small battery to an internal combustion engined car for regulatory and tax advantages and mark this as a job well done. PHEVs on the market today emit nowhere close to the low CO2 claimed; they are designed as a compliance trick for CO2 rules and to benefit from tax incentives. Their scandalous real-world performance, as this testing programme shows, risks to be another emissions scandal in the making. Carmakers and regulators should move away from the current “fake electric” technology as soon as possible.

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Abbreviations

EV	Electric Vehicle (*In this report, this stands for vehicles propelled by an electric motor: battery electric vehicles, fuel cell electric vehicles and plug-in hybrid electric vehicles*)
BEV	Battery Electric Vehicle
ZEV	Zero-Emissions Vehicle: BEV and FCEV
PHEV	Plug-in Hybrid Electric Vehicle
ZLEV	Zero and Low Emission Vehicles (Defined in Regulation EU 2019/631 as a passenger car or a van with CO_2 emissions between 0 and 50 g/km)
HEV	Mild and Full Hybrids
ICE	Internal Combustion Engine
SUV	Sports Utility Vehicle
Battery	Unless explicitly stated otherwise, in this report 'battery' refers to the high voltage battery used to power the vehicle. (Also known in WLTP regulation as the REESS: Rechargeable electric energy storage system).
WLTP	World harmonised Light-duty Test Procedure: Used for the type-approval of
light-duty	cars since September 2017.
NEDC	New European Drive Cycle: Used for the type-approval of light-duty cars until September 2017
UF	Utility Factor: The expected share of electric operation used for the type-approval of PHEV cars.

1. Introduction

1.1 Preamble

In 2016 Transport & Environment (T&E) together with the German NGO Deutsche Umwelthilfe (DUH) launched the 'Get Real – Demand fuel figures you can trust" (LIFE15 GIC/DE/00029)' project, funded by the European Commission's LIFE programme, to raise consumers' awareness about the gap between real-world fuel consumption of cars and to identify solutions to reduce the gap.

In the past few years, it has become apparent that a particularly large gap exists for plug-in hybrid vehicles (PHEVs). In order to investigate this further, T&E commissioned Emissions Analytics, an independent laboratory, to test three different WLTP-approved PHEVs: a BMW X5, a Volvo XC60 and a Mitsubishi Outlander. All three cars underwent on-road testing to measure the real world electric range, fuel consumption and CO2 emissions under various driving conditions. This report presents the results of this project.

The introduction of this report lays out background information relative to CO2 emission trends for transport in the EU and provides an overview of the issues surrounding PHEVs.

Section 2 provides details on the cars tested as well as the tests undertaken by Emissions Analytics.

Section 3 presents the results of the tests, notably on the electrical range, electrical consumption, CO2 emissions and fuel consumption results as measured during this testing programme.

Section 4 analyses the test results presented in section 3 including: the dependence of CO2 emission on trip distance and the EV-range which would be required for PHEVs to stay below official type-approval values.

Section 5 explains the regulatory framework that governs PHEV emission assessment and models the average real-world CO2 and fuel consumption performance of PHEVs .

Finally, **Section 6** details the policy changes necessary to ensure that PHEVs sold in the EU are able to deliver the required CO2 savings on the road.

1.2 Transport emissions: Still Europe's biggest climate problem

Passenger cars are responsible for around 12.5% of the EU's annual CO2 emissions[1] and are the number one contributor to transport's total CO2 emissions, accounting for a whopping 43% share. Increased car mileage, the rise of the SUV and a failure to reproduce lab based CO2 savings on the road have resulted in car's CO2 emissions growing by 18% since 1990 culminating in 543 million tonnes of CO2 emissions in 2017 alone[2]. However, with the European Green Deal's ambition of net zero CO2 emissions by 2050 and with the EU's pledge to reduce transport's CO2 emissions by 90% on the same time scale, CO2 emissions from passenger cars now have to decrease rapidly. In order to reach these goals, sale of zero-emission cars has to swiftly increase and the sale of new cars with internal combustion engines has to be phased out in the 2030's and at the latest by 2035[3].

The introduction of the 95g/km fleetwide car CO2 emission target (as measured on the outdated NEDC- New European Drive Cycle) for carmakers in 2020/2021[4] is supposed to halt and reverse the growth of cars' CO2 emissions as car makers are subject to hefty fines of €95 per vehicle for every gram above their CO2 emission target. This pushes manufacturers to increase the sales of low and zero emissions cars as well as make their engines more fuel efficient. T&E's report[5] released last month suggests most car makers are on track or close to meeting their targets for 2020 through a mixture of increased sales of electrified vehicles as well as exploitation of legislative flexibilities and better engines (including non-chargeable hybrids). Indeed, sales data from the first quarter of 2020, suggests that new car CO2 emissions may experience their biggest fall since 2008, in H1 alone dropping by 11g/km. Meeting the standards will likely result in 10% plug-in market share in 2020, raising further to 15% in 2021.

In order to comply with current and future targets - further CO2 reductions of 15% and 37.5% are set for 2025 and 2030 and are likely to be revised upwards in 2021 - many car makers have looked to electrification, by producing more plug-in hybrid and battery electric vehicles than ever before.

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[1] European Commission. https://ec.europa.eu/clima/policies/transport/vehicles/regulation_en. Accessed 11/10/2020.
[2] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.
[3] T&E. (2018) How to decarbonise European transport by 2050.
[4] (EC) No 631/2019
[5] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.

Indeed electrification is now the long-term industrial strategy of many car makers including the VW Group, the Renault-Nissan-Mitsubishi Alliance, BMW and Hyundai-Kia with €60 billion invested in European electric vehicle (EV) production in 2019 alone[6].

Yet, while the climate benefits of 100% electric cars cannot be doubted, the environmental benefits of mild hybrid (MHEV), hybrid (HEV) and plug-in hybrids (PHEV) - which car makers are churning out in their thousands - are less clear, with data suggesting that their real world CO2 benefits are likely to be much smaller than official figures suggest. For PHEVs in particular the real world fuel consumption and CO2 emissions have been reported to be on average two to three times the official figures[7]. This is a colossal gap which makes the type-approval and real world gap for conventional cars, which at its worst was 42%[8] in 2017, pail in comparison. Such a large gap would severely undermine the EU's efforts to reduce car's CO2 emissions and hit consumer's pockets dearly.

This is especially a risk given that the sales of PHEV's are expected to massively increase over the next few years. This year alone PHEV sales are predicted to triple compared to 2019 with almost 500,000 PHEV's expected to be sold as manufacturer's push sales to aid CO2 compliance. Indeed, some including Jaguar-Land Rover, Volvo and BMW are relying predominantly on the sale of PHEVs to get them over the line. Indeed, PHEVs made up 22.6% of Volvo's total vehicle sales in the first quarter of 2020[9].

[6] T&E (2020). Can electric cars beat the COVID crunch?.
[7] T&E. (2020) UK briefing: The plug-in hybrid con.
[8] T&E. (2018) Ending the cheating and collusion: Using real-world CO2 measurements within the post-2020 CO2 standards.
[9] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.

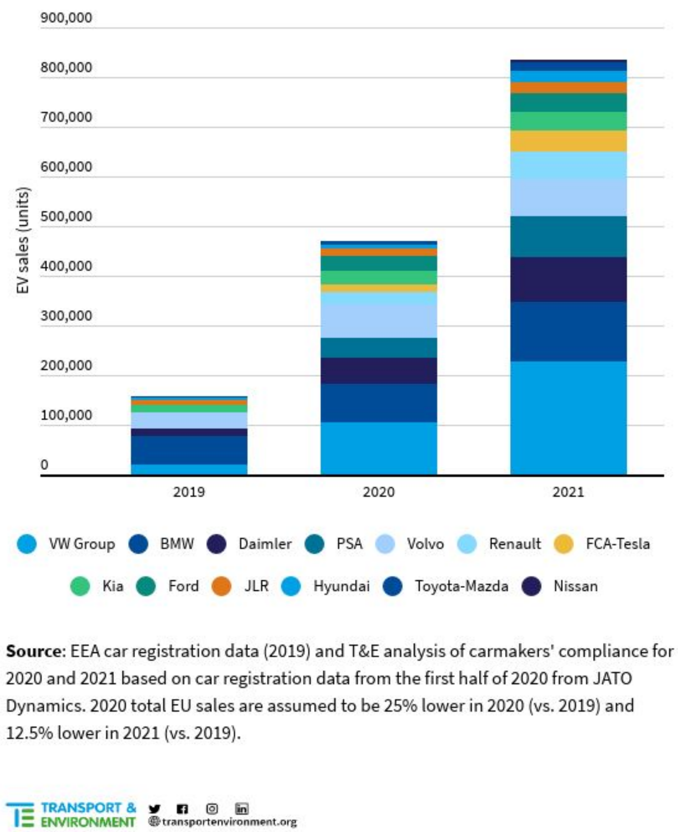

Figure 1: European PHEV sales 2019-2021

T&E expects the sale of PHEV's to almost double again in 2021, as CO2 targets fully come into force, with 840,000 units expected to be sold in 2021. With further decreases in fleetwide CO2 targets in 2025 and 2030 it is expected that PHEV sales and their market share will continue to grow until 2030[10]

1.3 What are plug-in hybrids?

Plug-in hybrids (PHEVs) are cars which are fitted with an internal combustion engine (ICE), electric motor and a high voltage (HV) battery which are all used to power the vehicle. The battery

[10] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.

can be charged externally just like a fully electric car hence the term 'plug-in' and is significantly larger than a battery on a conventional hybrid, but (usually) smaller than one fitted to a BEV. In order to tailor the use of the engine, electric motor and battery to the needs of the owner, most PHEVs on the EU market are equipped with four or more different driver selectable modes which are programmed by the car manufacturer to utilise the ICE, electric motor and battery differently. As such, all modes present on a PHEV will have different fuel/electrical consumption figures as well as CO2 emissions.

1. **EV predominant mode:**
   Typically a PHEV will have an 'EV only' or 'EV predominant' mode which primarily uses the battery to power the vehicle and depending on manufacturer may be advertised as zero emission. For example Ford's PHEV Kuga is advertised as having a zero emission range of up to 56km's[11], Mercedes' C Class Saloon PHEV of 54 km's[12] and the VW Passat of up to 56km, with VW even claiming that 'the majority of your day-to-day journeys in urban settings are emissions-free'[13] by driving in such a mode. For regulatory purposes such a mode is known as charge depleting.
2. **Hybrid mode(s):**
   There are usually several hybrid modes which behave similarly to a conventional non-plug-in hybrid and use a mixture of the combustion engine, battery and electric motor to power the vehicle. Hybrid modes vary by model and manufacturer, but sometimes include choices such as an 'eco hybrid' mode designed to maximise fuel efficiency, a 'sport mode' to maximise performance and an even an 'off road' mode. For regulatory purposes this mode is also known as charge depleting.
3. **Internal combustion engine (ICE)-only mode:**
   Anytime the car is driven on an empty battery, either because the battery has not been charged or because it has become depleted to the minimum state of charge allowed, the

[11] https://www.ford.co.uk/shop/research/hybrid-electric/plug-in-hybrid. Accessed 14/09/2020.

[12] https://www.mercedes-benz.co.uk/passengercars/mercedes-benz-cars/eq/phev-range.module.html?csref=mc_sem_cn-PC_BR_PROS_BrandMercedes_Core_Exact_ci-Google_si-g_pi-kwd-985301095567_cri-453036057063_ai-PPC2007080005_&kpid=go_cmp-10704174879_adg-106997128713_ad-453036057063_kwd-985301095567_dev-c_ext-&gclid=EAIaIQobChMImdnym6zo6wIV1O3tCh1h5wrfEAAYASAAEgLDs_D_BwE. Accessed 14/09/2020.

[13] https://www.volkswagen-newsroom.com/en/press-releases/new-passat-gte-with-longer-electric-range-5259. Accessd 14/09/2020.

PHEV is then powered almost exclusively by either its petrol or diesel engine. There may be a small contribution from the energy recouped from regenerative braking but this is minimal compared to the contribution of the ICE. Sometimes there is also a driver selectable 'battery hold' mode which allows the vehicle to maintain the battery fully charged while using only the combustion engine to power the car, e.g. until the owner needs the car to be driven in electric only mode to enter zero or low emission zones. This kind of mode is officially called charge sustaining in regulations.

4. **Battery charging mode:**
   Lastly, a battery charging mode may be available where the internal combustion engine is used both to power the car and charge the battery. Such a mode can be used to e.g. charge the battery while approaching a zero emission zone, or in the future, a zone using geo-fencing technology. From a regulatory point of view this is called charge increasing operation or charge sustaining charge increasing operation.

1.4 PHEVs: not what they seem?

The original idea for plug-in hybrids, prior to the development of battery technology which made pure electric cars capable of an electric range of 300km+, was to ease driver's range anxiety while still delivering some of the benefits of an electric car including lower CO2 and pollutant emissions. For those who feared running out of charge, the ICE was predominantly supposed to be a back-up option.

However, many of the models that have hit the EU's roads in the past 5 years do not appear to fit this criteria. Most are large SUV, C class or bigger vehicles, the average weight of a PHEV sold in 2019 was 39% higher than the average ICE[14]. Most are fitted with relatively small batteries, especially compared to the size necessary for the equivalent BEV and are therefore mostly only capable of a very limited electric range of between 30-60 km (as determined on official tests[15]). Yet, consumer experience suggests that in the real world many fall far short of even this limited range. Volvo, which now offers a PHEV option on all of its models, admits on its website that

[14] EEA. Monitoring of CO2 emissions from passenger cars-2019 provisional data.
[15] New European Drive Cycle (NEDC) prior to and the new World harmonised Light Duty Procedure (WLTP) from September 2017.

depending on the driving style, temperature and climate the electric range of it's PHEVs can decrease by up to 50% with some models only achieving a minimum range of 20km[16].

More worryingly the UK's *The Guardian* reported earlier this year that zero emission driving in PHEV's can be impossible altogether if auxiliaries including heating or adaptive cruise control are active and that some models may also switch on the ICE if more power is required than the electric motor can provide, for example due to fast accelerations or high speeds[17]. In some cases this may even happen without alerting the driver, with the vehicle supposedly still driving in 'zero emission' mode. These or similar restrictions were found to be present on all 11 of the UK's best selling PHEV models[18]. For comparison the longest range BEV's such as the Tesla Model S , Jaguar I-pace and Kia E-Niro have an estimated real world range of 512km, 360km and 368km[19] respectively and even the more budget Peugeot e-208 can now achieve a range of up to 347km[20], presumably unhampered by the use of auxiliaries or fast accelerations.

The reports of low real world EV-only range and potential inability to be driven in zero emission mode cast doubt on whether PHEV's are actually designed to operate in fully electric mode in the real world or if these vehicles are purely sold as compliance cars to help manufacturer's meet new CO2 standards. Despite their large size and low electric range (even in official figures) many PHEV's are certified as having CO2 emissions of less than 50g/km -sometimes less than a fifth of an equivalent ICE only car- which allows them to benefit from generous tax or purchase incentives in many Member States (including post COVID), as well as flexibilities in the EU cars CO2 regulation to more easily meet fleetwide CO2 targets. In some Member States PHEVs also get a zero emission label allowing them to access low emissions zones where conventional cars may not be permitted to enter or may be charged for doing so.

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16 https://www.volvocars.com/uk/support/topics/use-your-car/hybrid-related-information/range-in-electric-mode-for-twin-engine 07/09/2020

17 https://www.buyacar.co.uk/cars/economical-cars/hybrid-cars/820/best-plug-in-hybrid-cars-2019. Accessed 14/09/2020

18 https://www.theguardian.com/business/2020/mar/01/hybrid-carmakers-accused-of-con-over-zero-emissions-claims. Accessed. 07/09/2020

19 Data obtained from EV-database. Accessed 21/10/2020.

20 https://www.peugeot.co.uk/showroom/new-208/e-208/?&gclid=CjwKCAjw_Y_8BRBiEiwA5MCBJmJ0R4BgvJR1pMETczkV_JaPmok2-N8vBm8eNYjJiJsMTTlEayfI4hoC_McQAvD_BwE&gclsrc=aw.ds. Accessed 13/10/2019

At type-approval CO2 emissions of a PHEV are calculated based on very optimistic assumptions on how often a PHEV is charged (daily) and the share of electric kilometers driven for a given electric range (known as utility factors), assumptions which are not underpinned by real world data of PHEV use. For example, for a PHEV with a type-approval electric only range of only 50 km, it is assumed that the car spends almost 80% of its total km's in a charge depleting mode. Consequently, if the owner of such a car doesn't use a charge depleting mode at least 80% of the time, the real world CO2 emissions as well as fuel consumption will be far above type-approval values. However, studies by the European Commission's Joint Research Center[21] as well as the Association for Emissions Control by Catalyst (AECC)[22] on early Euro 6 PHEVs, have shown that CO2 emissions vary drastically depending on the driving mode that a PHEV is tested in and often exceed type-approval CO2 emission values many times over.

In September of this year the International Council on Clean Transportation (ICCT) in collaboration with the Fraunhofer Institute for Systems and Innovation Research conducted a large-scale analysis of the real-world usage of PHEV's, in Europe specifically focusing on data obtained from users in Germany, the Netherlands and Norway[23]. They found real world usage of PHEV's diverged significantly from what was assumed by the regulation with a big gap between official and real world utility factors of up to 4 times, with a particularly large gap seen for company cars. Providing further evidence that the way in which these vehicles are assumed to operate in the Regulation is not representative of their use in the real world.

1.5 This report

The growth in the sale of PHEVs is a huge potential risk to the EU's efforts to reduce car's CO2 emissions if PHEVs real world emissions exceed those assumed at type-approval. In order to investigate the real world performance of PHEVs, including the vehicle's electric only range, CO2 emissions and fuel consumption, T&E commissioned Emissions Analytics, developers of the EQUA database[24], an independent database of real world emission tests, to independently undertake on-road testing of three best-selling PHEV's passenger cars in the summer of 2020.

[21] JRC. (2019). On-road emissions and energy efficiency assessment of a plug-in hybrid electric vehicle.
[22] Demuynck. J., (17th-18th October 2017). Real Driving Emissions from a plug-in hybrid electric vehicle (PHEV). IQPC RDE Conference Berlin.
[23] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.
[24]https://www.emissionsanalytics.com/real-world-test-database

This report presents the results of this testing project and combines the real world test data with the latest research on the real world usage of these cars from the ICCT/Fraunhofer Institute study in order to assesses whether PHEV technology is really as good for the climate as the car industry suggests or whether PHEVs are just another ploy by the car industry to continue selling gas guzzling ICE cars for as long as possible.

While pollutant emissions of nitrogen oxides (NOx), carbon monoxide (CO) and the number of particles (PN) were also measured, their emissions were found to be below the Euro 6 RDE limits and will not be discussed further in this report.

2. Methodology

In the summer of 2020 T&E commissioned Emissions Analytics (EA) based in High Wycombe, United Kingdom to undertake real world testing of PHEVs under a range of different on road driving conditions in order to investigate the vehicles real world electric range, CO2/pollutant emissions as well as fuel and electrical consumption.

2.1 The cars

Three PHEV SUVs were chosen by T&E for testing: a BMW X5, a Volvo XC60 and a Mitsubishi Outlander. The cars were chosen based on their 2019 sales volume and in the case of the BMW its type-approval electric range, which at 81km (WLTP), is industry leading. All three cars were of the Euro 6d-temp emission standards approved under the WLTP regulation and were sourced independently of T&E by Emissions Analytics. Further details of the tested vehicles are available in Annex 1.

Figure 2: The three PHEVs tested by Emissions Analytics; BMW X5, Volvo XC60 and Mitsubishi Outlander

2.2 The tests

Three different on-road test routes were developed by EA. The first route was fully compliant with the 4th package of the Real Driving Emissions (RDE) regulation used for pollutant emissions type-approval of light-duty cars and represents a mild/moderate style of driving. It should be noted that RDE testing is not currently used for the type-approval of cars in relation to their electric range, CO_2 emissions, electrical or fuel consumption but the test RDE procedure provides a useful and comparable framework for on-road testing of passenger cars and therefore was used as a template for the design of test routes used during this testing programmes.

Each car was tested four times on the RDE compliant route as follows:

1. **EV predominant mode test:** The test was started with a full battery[25] and the EV predominant mode was selected by the driver at the beginning of the test upon vehicle ignition. As such each car should have been driving in predominantly electric mode at the beginning of the test followed by the default mode selected by the car once the battery was depleted.
2. **ICE mode test:** The test was started with a fully depleted battery[26] and the driver selected the driving mode on each PHEV where the internal combustion engine is predominantly used to power the car. On the X5 this meant the "battery hold" mode (set at the

[25] At the maximum state of charge.
[26] At the minimum state of charge allowed by the car.

minimum 30% battery state of charge allowable by the car) was the closest mode to ICE-only on the X5. This resulted in the battery charging up to a minimum 30% state of charge at the beginning of the test.

3. **Charging mode test:** The test was started with a fully depleted battery and the driver selected the battery charging mode at the beginning of the test. This meant that the internal combustion engine was used to both power the car and charge the battery during the test. Once the battery was fully charged the test continued in the mode selected by the car.
4. **Maximum load test:** In this test the car started with a fully charged battery as per the EV mode test. However, the load placed in the car was increased to the maximum load allowed for each car; 750kg for the X5, 550kg for the XC60 and 475kg for the Outlander[27].

The other two test routes are non-RDE complainant and were designed to test how the PHEV's performance is affected by different driving and road conditions which fall outside of the boundaries of the RDE regulation. All three cars were tested once on each RDE non-compliant route as follows:

5. **Dynamic/Elevation test:** The second test route was designed to test the PHEVs under more challenging driving conditions, focusing on a more dynamic driving style (with harsher accelerations) and greater altitude gain than allowed by the RDE test procedure. The test started with a fully charged battery and the driver selected the same predominantly electric mode as used in the EV-predominant test upon ignition of the car.
6. **Reverse order test:** The third test route was designed to test the effect of motorway driving on EV range and the route does not follow the traditional urban, rural and motorway route used for RDE testing. The route starts with a very short urban section followed by motorway driving until the PHEV's battery is depleted and the ICE is switched on. This is followed by a further 5km's driving on the motorway before transitioning to a mixture of urban and rural driving. ThePHEVs started the test with a fully charged battery and the driver selected the same predominantly electric mode upon ignition of the car as used in the EV-predominant test.

[27] It should be noted that the load used on this test is beyond the boundaries of the RDE regulation which allows a maximum vehicle load of ≤ 90% of maximum vehicle weight.

Further details of the test routes are available in Annex 2. Auxiliaries were used in a manner typical of every-day use and kept constant between tests; the air conditioning was set at 19 ^{0}C, fan speed medium, the radio was on and lights set to 'Auto'. The vehicle load was set to 300 kg on all tests (except test 4, max load test) and reflects the weight of the equipment used to measure emissions and electricity use as well as the weight of the driver. From a regulatory perspective this is equivalent to a load of 4 average adults (75kg each). All tests were performed in good weather with temperatures of between 17-25^{0}C. Prior to the start of testing all vehicles underwent a mechanical fitness check including a scan of the on-board diagnostic fault codes and were found to be in sound mechanical condition.

The vehicles CO_2 and pollutant emissions (NO, NO_2, CO) were measured continuously at the tailpipe at a frequency of 1Hz using Sensors' SEMTECH-LDV Portable Emissions Measurement System (PEMS), particle number emissions were measured using Sensors Condensation Particle Number (CPN). The vehicle's electrical consumption was measured independently of the vehicle using a 1,000-amp CT6846 battery clamp produced by Hioki Corporation also at a frequency of 1Hz. On-board diagnostic channels were monitored using a CAN connection, however it should be noted that no channels relating to the operation of the PHEV's high voltage battery were available on any of the three cars tested.

3. Results

This section of the report outlines the results of this testing campaign including the electric range, electric consumption, CO_2 emissions and fuel consumption of the BMW X5, Volvo XC60 and Mitsubishi Outlander PHEVs tested. Results are compared official figures obtained from each car's certificate of conformity (CoC).

3.1 Electric range

The electric range of a PHEV is critical for the determination of a PHEV's CO_2 emissions and fuel consumption at type-approval. Therefore, any discrepancy between type-approval and real world electric range has the potential to create a gap between type-approval and real world figures thereby leading to unrepresentative CO_2 emissions being used. It can also mis-lead customers into buying cars which are not capable of the performance expected of them.

Given recent reports that the EV-only range of PHEVs may be reduced when driven in the real world outside of optimal driving conditions or when certain auxiliaries such as window demisters are used, T&E wanted to investigate what impact different vehicle and driving conditions have on the real world electric range of PHEVs and whether these cars are actually capable of driving in EV-only mode on the road. The EV-only range as measured on tests 1-4 as well as the official NEDC and WLTP weighted combined and WLTP city ranges are presented in figure 3. The EV-range reported for tests 1-4 is based on the first ignition of the combustion engine during each test as for consumers this is the electric range that matters.

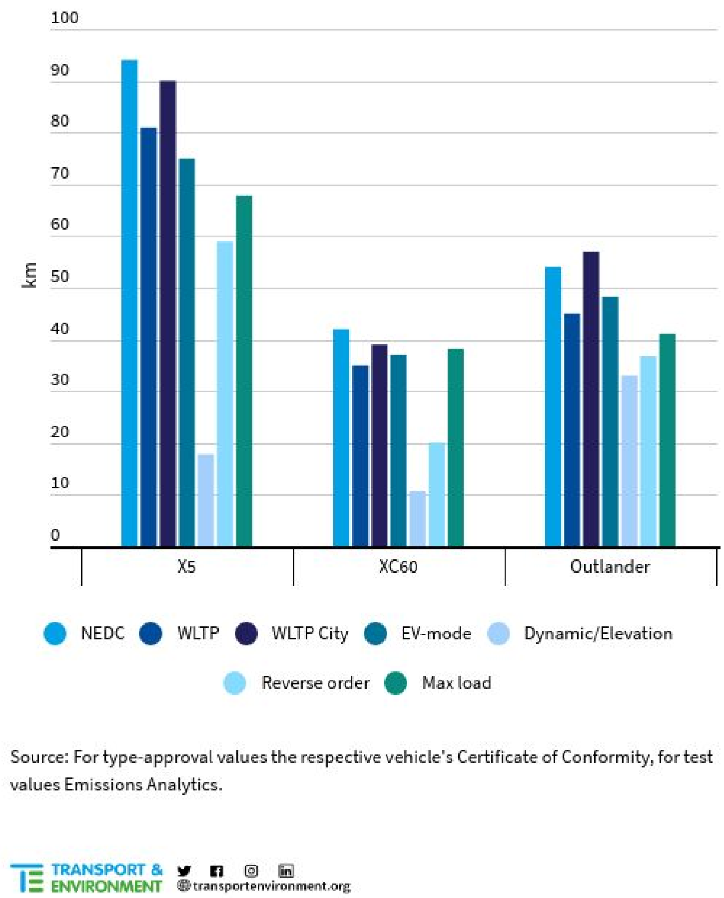

Figure 3: The real world EV-only range of the three PHEVs tested and the type approval electric ranges (NEDC, WLTP, $WLTP_{CITY}$) as provided on the respective car's certificate of conformity.

3.1.1 Electric range under mild driving conditions

The first on-road test (EV predominant mode) was designed to test the EV-only range of the PHEVs under mild/moderate driving conditions in line with the requirements of the EU Real Driving Emissions (RDE) test procedure[28]. Previous on road testing conducted by T&E and PSA Group has shown that staying within the driving boundaries of the RDE procedure[29], especially for larger vehicles (such as the three tested within this programme), may in some cases underestimate the performance demanded from these cars by the typical consumer. This test was therefore deemed suitable as a baseline for the mild on-road test to assess if the three PHEVs were capable of the performance advertised under what can be considered as average driving conditions.

Under these mild/moderate driving conditions it was found that the EV-only range of the PHEVs tested was close to or surpassed the WLTP electric range[30] stated on the vehicle's certificate of conformity (figure 3). The X5's range was 7% lower than at type-approval achieving an EV-only range of 75km. On the other hand, both the XC60 and the Outlander exceeded the WLTP range by 6% and 7%, achieving a EV-only range of 37km and 48km respectively.

Some of the difference in on-road and WLTP electric range can be attributed to the difference in methodology used for their calculation. For the purpose of this testing programme, the electric range was considered to be the first ignition of the engine on the test as this is the EV range that matters to consumers, essentially how far a PHEV can drive without the ICE[31]. However, the WLTP method is based on how far the car can drive in a charge depleting mode - i.e. as long as the battery/electric motor is used - before the battery is fully depleted[32], even if the ICE kicks in and the vehicle drives in hybrid mode during this time. The share of that total distance attributed to electric energy, prior to the depletion of the battery is then calculated and known as the 'Equivalent All Electric Range (EAER)', contained in the car's CoC. In practice, reporting only the

[28] Used for the testing of the on road pollutant emissions performance of passenger cars during type-approval as well as during in-service conformity tests.
[29] Such as driving dynamic, predominantly acceleration.
[30] Equivalent All Electric Range (EAER)
[31] In the WLTP regulation this is also known as the 'All electric range', for further information please see section 6.3.2.
[32] Defined as when the relative energy change of the high ovulate battery is less than 0.04. The criteria for selecting the charge depleting mode used for the test is available in (EC) No 1151/2017

EAER means manufacturers can advertise a longer electric range for PHEVs than the cars can actually achieve in a zero-emission mode.

The difference in the size of the gap between the WLTP and the real world EV-range of the X5 compared to the XC60 or Outlander can potentially be explained by the difference in the real world electrical range between the three cars tested and therefore the type of driving that the vehicles were operating in during the EV-only part of the test. City only driving results in a longer electric range, as attested by the official city EAER[33] which is reported as 90km for the X5, 39km for the XC60 and 57km for the Outlander, longer than the EAER for all three cars.

The XC60 and Outlander, with their shorter EV-only range, were only operated in EV-only mode during the urban and rural part of the test, likely resulting in a longer EV-only range than had they also driven on the motorway. The X5, however, with its longer electric range was also operated in EV-only mode during the motorway part of the test which is associated with higher electric consumption than urban or rural driving, potentially resulting in a lower EV-only range than if the car had been driven only in the urban or rural sections of the test.

Electrical consumption

During this test the X5 consumed 222 Wh/km (20.4 kWh in total), the XC60 97Wh/km (8.9 KWh in total) and the Outlander 96 Wh/km (8.73 kWh in total) over the entire test. During the test, the combustion engine first came on after 69% of total battery capacity was used by the X5 (or 16.44kWh), 52%(5.37kWh) for the XC60 and 35% (4.83KWh) for the Outlander. It should be noted that after engine start the electrical consumption from the battery of the X5 was negligible (0.4kWh). This was also the case for the XC60 (0.22kWh), however due to the wiring set-up of the vehicle and the position of the measurement clamp it is impossible to tell if this came from the engine (via the generator) or the battery. It is also impossible to tell this for the Outlander but 2.0kWh were consumed by this vehicle post-ICE start. However, as a similar level of electric consumption was seen during the ICE-only test, it is likely that the majority of this came from the engine, not the battery.

The electrical consumption during the EV-only part of the test i.e. when the internal combustion engine was not running was 263 Wh/km (19.7kWh) for the X5, 196 Wh/km (7.26kWh) for the XC60 and 120Wh/km (5.82kWh) for the Outlander. For the X5 this is 5% higher that the type-approval

[33] Is the Effective All Electric Range determined on the WLTP city cycle, this is further discussed in section X.

WLTP consumption[34] of 249Wh/km. For the XC60, the gap was bigger at 22%, (type-approval = 160Wh/km). In Contrast for the Outlander the consumption was 29% lower compared to the 169Wh/km measured at type-approval.

3.1.2 Electric range under more dynamic driving conditions

Although all three vehicles are able to achieve close to the official WLTP EV range in EV-only operation under mild/moderate driving conditions, the EV-only range of all three PHEVs was significantly reduced when driven under more challenging driving conditions. The largest decrease in EV-only range occurred when driving more dynamically (with sharper accelerations) and with greater altitude gain than allowed by the RDE regulation.

The largest decrease was observed for the X5, cutting the EV-only range by 76% to only 17.6km. For the XC60 the decrease was of a similar magnitude of 71%, achieving only 10.7km. The Outlander performed slightly better achieving 33km of EV-only range, a reduction of 32%. While on this test the energy consumption during EV-only operation (compared to the EV-predominant test) increased by 57% to 413 Wh/km for the X5, by 49% to 180 Wh/km for the Outlander, for the XC60 the EV consumption decreased on this test to by 21% to 155 Wh/km[35]. Such a large drop in the EV-only range for the X5 and XC60 cannot be explained by differences in EV consumption alone. On this test, the engine of the X5 and XC60 come on much sooner, after the battery was only depleted by 26% (6.31kWh) for the X5 and 14% (1.43kWh) compared to 69% and 52% on the EV-predominant test.

This suggests that the power from the electric motor and battery, as fitted, is insufficient to solely power these two cars when driven with sharp accelerations and greater altitude gain or that the power of the battery at this state of charge is already too low to provide full power to the electric motor. This is essentially a technology design limitation on the EV-only performance and operation of the two cars. In comparison, the Outlander shows no such performance limit. Its EV-only range was also reduced, but the engine only came on once the battery was depleted to a similar level (4.93kWh vs.4.83kWh) as in the EV-predominant test, most likely made feasible by the more powerful electric motor fitted to the Outlander.

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[34] As obtained from the vehicle's Certificate of Conformity (CoC)

[35] This is not comparable due to the very short EV-only range achieved during the test (10.7km)

3.1.3 Electric range under motorway driving conditions

It is well known that driving in EV-only mode in cities or urban areas can increase the electric range of both PHEV's and BEV's, predominantly due to slower average speeds reducing overall energy demand, and stop-start driving providing more opportunities for regenerative braking to occur. However, it is not usually reported how motorway driving (i.e .higher average driving speeds and less opportunities for regenerative braking) affect EV-range. There have been some reports that at higher driving speeds some PHEVs are unable to stay under EV-only operation[36].

While all three PHEVs were capable of EV-only operation during motorway driving, including speeds of up to 124 km/h, it was found that the higher driving speeds resulted in a sharp increase in the electrical energy consumption of all three PHEVs[37]. For the X5 the EV consumption increased by 20% to 317Wh/km, 74% for the XC60 to 341Wh/km and 7% for the Outlander to 129Wh/km. This in turn resulted in a decrease in the real world EV-only range of all three cars. The largest drop occurred for the XC60 almost halving the EV-only range to 20.1km. For the Outlander and the X5 the decrease was smaller at 24% and 21% respectively, resulting in a real world EV-only range of 36.8km and 58.9km respectively. The decrease in EV-only range during motorway driving will be of consequence for those PHEV users who predominantly drive on the motorway. This may particularly affect company cars which tend to drive longer distances and are therefore more likely to drive frequently on the motorway than privately owned cars.

3.1.4 Electric range of a fully loaded PHEV

In order to test the effect of payload on the EV-only range of the PHEVs, each PHEV undertook the RDE compliant route loaded to the maximum permissible payload for each car.

For the X5 and Outlander the higher payload (of an additional 450kg and 175kg respectively) resulted in an increase in electrical consumption of 15% (303 Wh/km) for the X5 and 18% (143 Wh/km) for the Outlander, compared to the EV-predominant test. This resulted in a decrease of the EV-only range by 10% for the X5 and 15% for the Outlander. The smaller than expected decrease in EV-only range for the X5 is likely due to the X5 consuming an additional 1.13kWh prior

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https://www.theguardian.com/business/2020/mar/01/hybrid-carmakers-accused-of-con-over-zero-emissions-claims 07/09/2020

37 It has to be noted that battery electric cars also see their electric range dropping in high speed/motorway style driving.

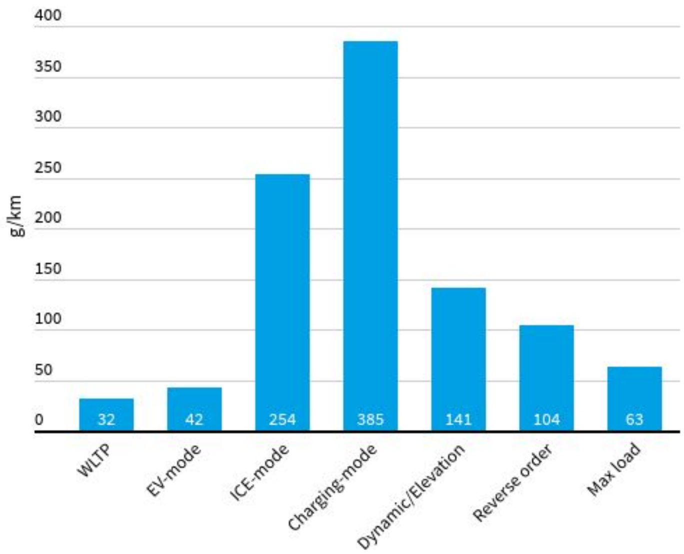
to ICE start on this test, whereas for the Outlander the switch point remained constant. For the XC60 the EV-only range was largely unaffected when the load was increased by 250kg, even increasing by 3%, despite the EV consumption increasing by 9% to 2019kWh/km, which may be explained by an additional 0.44 kWh consumed prior to ICE start, compared the the EV-predominant test.

3.2 CO2 emissions

The results of T&E's testing show that type approval CO2 emissions of the three PHEVs tested are largely not representative of the real-world trip emissions; in some cases CO2 emissions exceed official values up to 12 times.

3.2.1.CO2 emissions of the BMW X5

The high real world EV-only range of the BMW allowed the car to achieve relatively low CO2 emissions during the EV-predominant test, averaging emissions of 42g/km, the closest any of the three PHEVs got to achieving official CO2 values. While this is below the 50g/km of CO2 threshold - used as a qualification of a low emission vehicle for the EU CO2 regulations -, this car still exceeds the official type-approval CO2 value of 32g/km by almost a third. This is surprising given that during this test the X5 spends 82% of the total test km's driving in electric only mode during which no CO2 emissions are produced. However, the vehicle's CO2 emissions soared as soon as the internal combustion engine switched on.



Source: WLTP data from the vehicle's certificate of conformity, test data from Emissions Analytics

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Figure 4. Real world and official (WLTP) CO2 emissions of the X5.

The X5's CO2 emissions were then measured on the same test route but starting with an empty battery with the ICE predominantly powering the car (ICE-mode). During this test CO2 emissions increased significantly to 254g/km, or eight times higher than the official WLTP value. As part of the mode that this vehicle was tested in, the vehicle maintained the battery state of charge at 30% during the test. This resulted in the car charging the battery by up to 5.94KWh using the engine mostly at the beginning of this test[38], which likely resulted in higher CO2 emissions than if no battery charging had taken place. However, according to Emission Analytics, a similar period of battery charging was observed when the X5 defaulted to hybrid operation, upon engine start, when the battery was at a low state of charge. So this may be the normal operation of the vehicle when the battery is low on charge. In any case the emissions were 17g/km (7%) higher than the charge sustaining (ICE-only) emissions as measured on the official WLTP test (254g/km vs.

[38] Due to the architecture of the electric wiring and the position of the measurement clamp it was not possible to distinguish between charging from regenerative braking and charging from the engine.

237g/km)[39]. This is within the average gap of 14% reported by ICCT between WLTP and real world CO2 values[40].

Even higher CO2 emissions were measured on the same test route but in the battery charging mode, where the ICE is used to both power the car and charge the battery. Total test emissions reached 385g/km, in excess of 12 times the WLTP CO2 emissions, particularly high emissions were measured during urban driving of 470g/km.

Total test emission in the remaining three on-road tests (dynamic/elevation, reverse phase and max payload) all starting in EV-predominant mode exceeded WLTP emissions by between 2-4 times. This is despite the car starting with a fully charged battery and running in EV-only mode at the beginning of the test.

From these results it is clear that the X5's CO2 emissions are highly dependent on driving style and operating mode selected. In conclusion, this PHEV appears to only come close to its official CO2 emissions when starting with a fully charged battery and driving under mild/moderate driving conditions.

3.2.2 CO2 emissions of the XC60

Of the three PHEVs tested during this testing programme, only the XC60 had both type-approval WLTP and NEDC CO2 emissions above 50g/km, meaning that it does not qualify for super credits or many of the tax breaks or subsidies discussed in section 6.4. However, despite higher official emissions of 71g/km, the XC60 failed to achieve close to this performance on any of the on road tests.

[39] As obtained by Emissions Analytics from BMW.
[40] ICCT. (2020) On the way to "Real-world" CO2 values: The European passenger car market in its first year after introducing the WLTP.

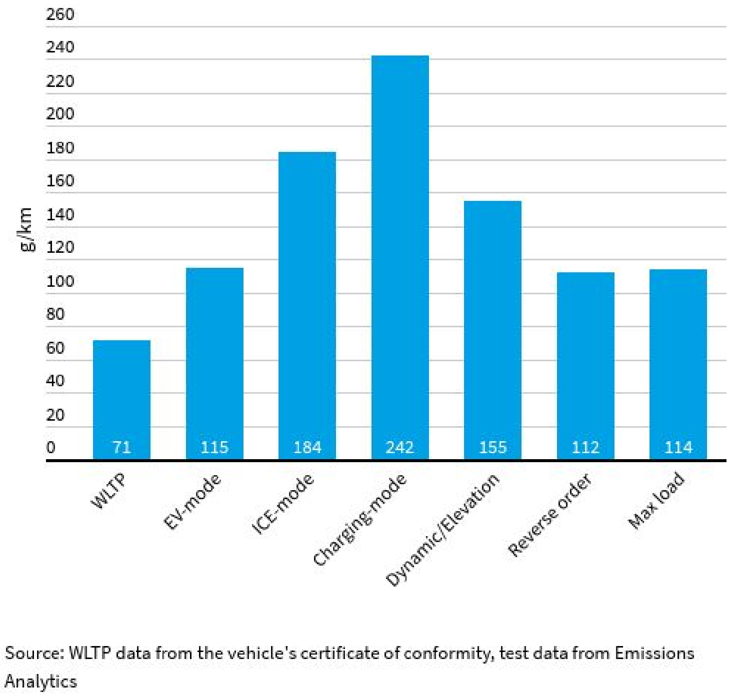


Figure 5. Real world and official (WLTP) CO2 emissions of the XC60.

This is predominantly due to the much shorter EV-only range of the XC60 resulting in the car spending 59% or more of total test km's driving with the internal combustion engine switched on on tests where the car started in an EV-predominant driving mode (EV-mode, dynamic/elevation, reverse order and max payload). This resulted in CO2 emissions of between 1.6-2.2 times the official WLTP value on these tests. As observed for the X5, the highest emissions occurred during the dynamic test, during which the EV-only range was reduced to 10.7km, emitting 155 g/km.

On tests where only the ICE was powering the car (ICE-mode), the CO2 emissions were lower than the X5, averaging 184g/km, or 2.6 times the WLTP value. This is at least partly due to the lower mass of the XC60 (2139kg vs 2510kg)[41]. The XC60's emissions during this test may have been

[41] Mass in running order.

slightly lowered by the fact that the car consumed 1.40KWh during this test, potentially coming from the battery[42]. The highest CO2 emissions overall were measured in battery charging mode, averaging 242g/km, more than three times the official WLTP emissions.

3.2.3 CO2 emissions of the Outlander

During the two tests where the ICE was used to power the Outlander (ICE-mode, Charging-mode), the car had the lowest CO2 emissions of the three PHEVs tested. This could be due to the lower weight of this PHEV (1955 kg), as well as the car largely running as a series hybrid with the engine providing electricity to the electric motor via a generator, rather than driving the wheels directly. Nevertheless, CO2 emissions were still 3-4 times higher than the official WLTP value. Even on tests beginning with a fully charged battery, CO2 emissions were 1.9-2.7 times higher than official figures. This is despite the car achieving a slightly higher EV-only range in the EV-predominant test than the official figure.

[42] However, as already mentioned due to the wiring set up of the car and the position of the measurement clamp it is impossible to verify if this came directly from the engine/alternator or from residual charge stored in the HV battery.

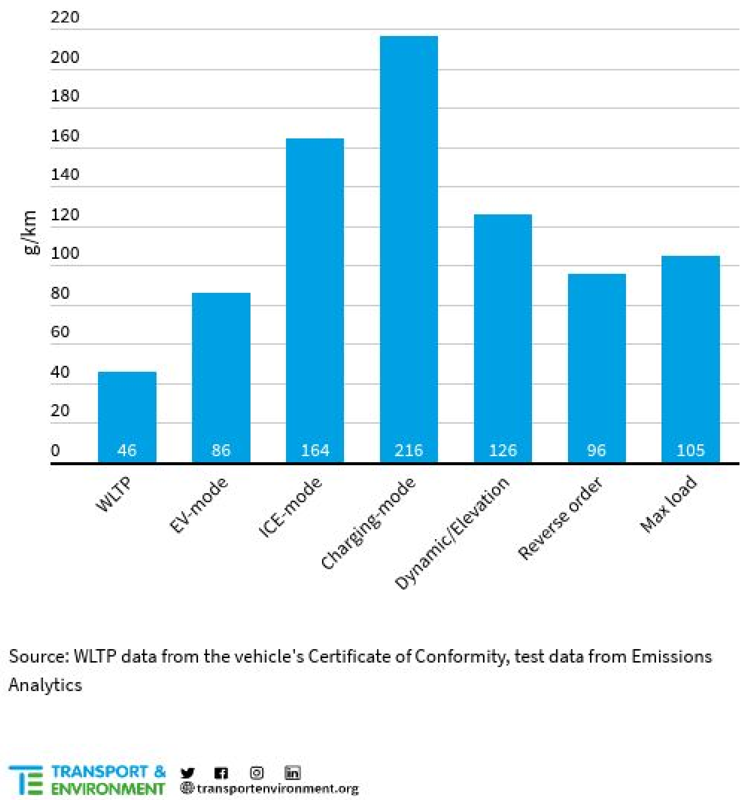


Figure 6. Real world and official (WLTP) CO2 emissions of the Outlander.

3. Fuel consumption

For consumers as well as companies who run commercial fleets or provide true fleet company cars, accurate fuel consumption figures are critical for assessing the total cost of ownership and the environmental impact of carx when making purchasing decisions. However, as the fuel consumption of PHEVs is calculated in the same manner as CO2 emissions, the official WLTP fuel consumption figures do not appear to accurately reflect the average real world usage of PHEVs. The following section presents the real world fuel consumption figures of the three tested PHEVs.

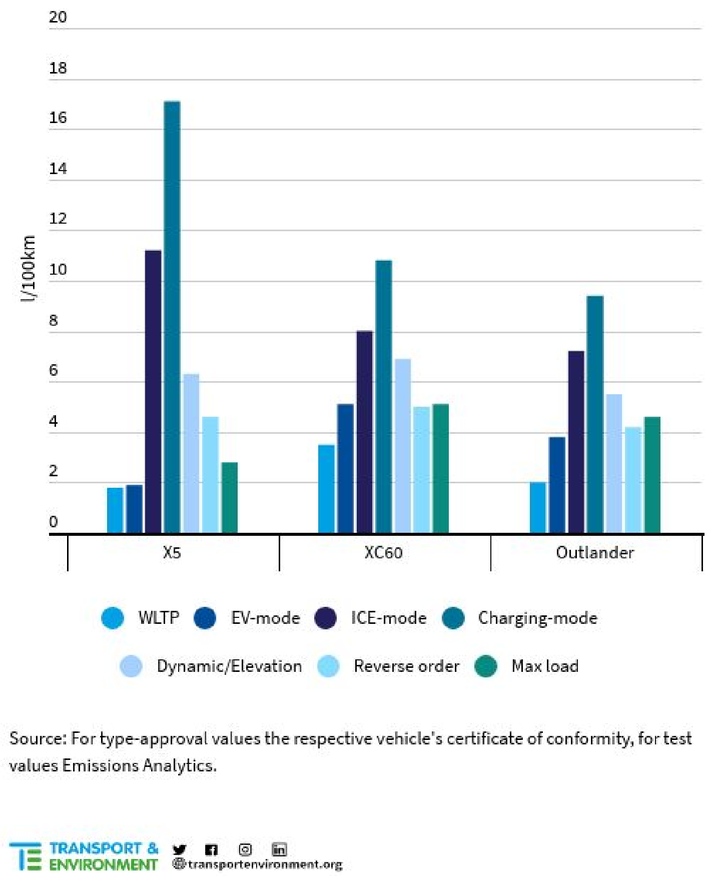


Figure 7: Real world fuel consumption of the three tested PHEVs as well as the WLTP fuel consumption as provided on the respective vehicle's certificate of conformity.

BMW X5

The fuel consumption of the X5 varied between 1.9l/km on the EV-predominant test to 17.1l/100km on the battery charging test, 9.5 times the official WLTP consumption of 1.8l/km. When driven outside of RDE conditions or with higher vehicle payload, fuel consumption varied between 2.8-6.3l/100km, thereby indicating that official WLTP fuel consumption can only be achieved under mild on-road driving conditions for this car starting with a fully charged battery.

Volvo XC60

The fuel consumption of the XC60 ranged between 5.0-10.8l/100km, exceeding the official WLTP value (3.5l/100km) by between 1.4-2 times. As expected, the highest fuel consumption was recorded on the charging-mode test.

Mitsubishi Outlander

The Outlander had similar variability in fuel consumption as the XC60 of between 3.8-9.4l/100km, exceeding the type-approval WLTP consumption of 2.0l/100km by between 1.9 and 4.7 times. As for the X5 and XC60, the highest fuel consumption was measured in charging-mode.

4. Why are CO2 emissions of the tested PHEVs so high?

The results in the previous section show that CO2 emissions, fuel consumption and electric-only range vary greatly depending on the operating mode and manner in which PHEV vehicles are driven. On all tested trips real world fuel consumption and CO2 emissions largely fail to match those determined at type-approval and advertised for the vehicle. This next section explores the reasons for such high CO2 emissions and fuel consumption from the tested PHEVs individual trips.

4.1. CO2 emissions are highly dependant on the distance driven

Total trip CO2 emissions and fuel consumption from a PHEV are highly dependent on the share of EV vs. ICE operation on the trip When starting a trip with a fully charged battery, the CO2 emissions are determined by the EV range of the vehicle, the length of the trip, the power demand on the battery (determined by driving conditions and auxiliary use) and the CO2 emissions once the ICE kicks in. Longer trips, where the battery becomes depleted and the ICE has to be used for longer, lead to higher overall CO2 emissions and fuel consumption. In practice this means once PHEVs run low on battery charge and have to switch on the ICE, there is only a very limited distance that they can drive before exceeding official CO2 values for the entire trip distance.

4.1.1 Measured maximum trip distance for PHEVs to stay under type-approval limits during the different tests

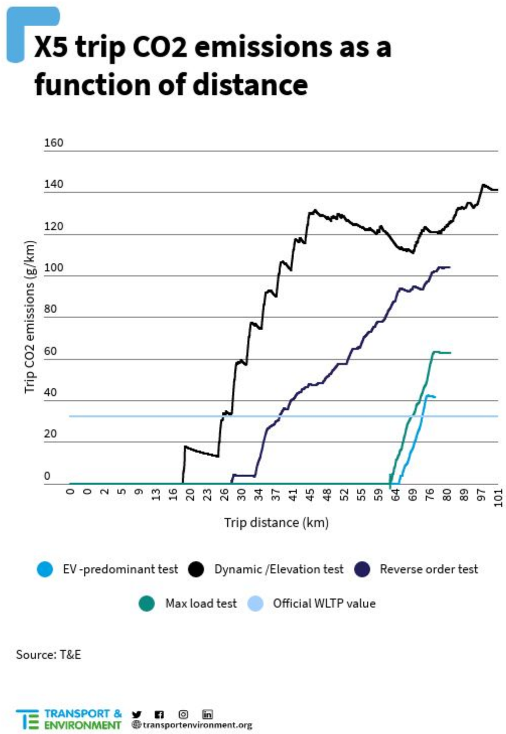
Figures 8-10 show trip CO2 emissions of the three PHEVs as a function of trip distance, for all tests starting in EV-predominant mode. As can be seen, total trip CO2 emissions are highly dependent on the EV-only distance driven as well as the total length of the trip. On trips where the electrical consumption is higher, the vehicles switched the ICE on sooner and the CO2 emissions also tended to be higher. The *compliance distance* (C_D) during which the PHEVs stayed below their official WLTP CO2 values varied significantly between tests.

The longest C_D for all vehicles occurred during the EV-predominant test. Of the three cars tested, the X5 had the longest C_D of 87km under these driving conditions; this is unsurprising given that the model boasts one of the longest EV ranges of PHEVs on the market. This was slightly reduced to 79-80km during the RDE non-compliant reverse and max load tests, mainly due to reduced EV-only range as described in section 3.1. However, the inability of the X5 to stay in EV-only operation for long during the dynamic test and high CO2 emissions once the ICE switched on had a large impact on the C_D, reducing it to only 26km. This is disappointing given that the car is fitted with a 24kWh battery, which is the same size as the earlier battery electric version of the Nissan leaf which is estimated to have an electric range of between 86-200km[43].

Under EV-predominant operation, the XC60 had a lower C_D range of 62km. However, under dynamic driving conditions the car was also not able to stay in EV-only operation for long, resulting in a much shorter C_D of only 26 km. In the reverse phase test the C_D was less affected by the more challenging driving conditions achieving a C_D of 56km. On the max load tests the XC60's C_D remained at 62km.

The Outlander had a C_D range of 67km under EV-predominant operation. This was reduced to 46km under dynamic driving conditions, a comparatively smaller reduction than was observed for the X5 or XC60. This is likely due to the more powerful EV motor fitter to the car, which allowed the car to stay in EV-only operation until the battery was depleted to a similar level as in other tests. During the reverse phase and max loads test the C_D was reduced to 61km and 63km, respectively.

[43] https://ev-database.uk/car/1019/Nissan-Leaf-24-kWh. Accessed 14/10/2020.



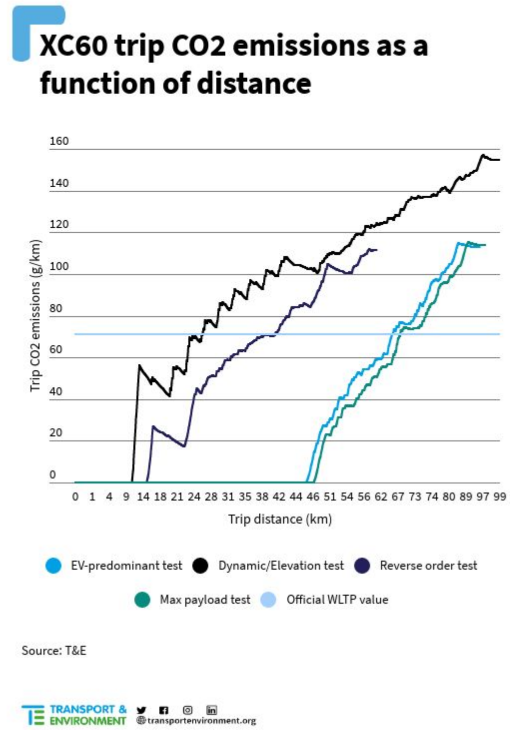


Figure 8 and 9: Real world CO2 emissions of the X5 and XC60 as a function of distance, for tests starting in EV-predominant mode.

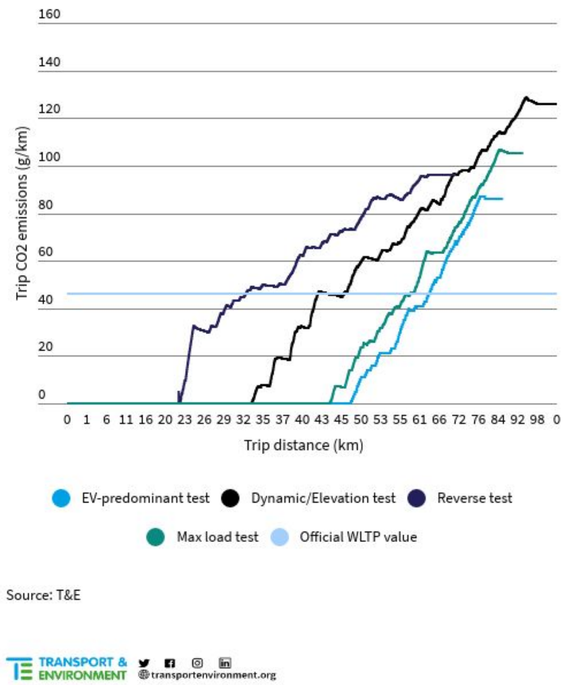


Figure 10: Real world CO2 emissions of the Outlander as a function of distance, for tests starting in EV-predominant mode.

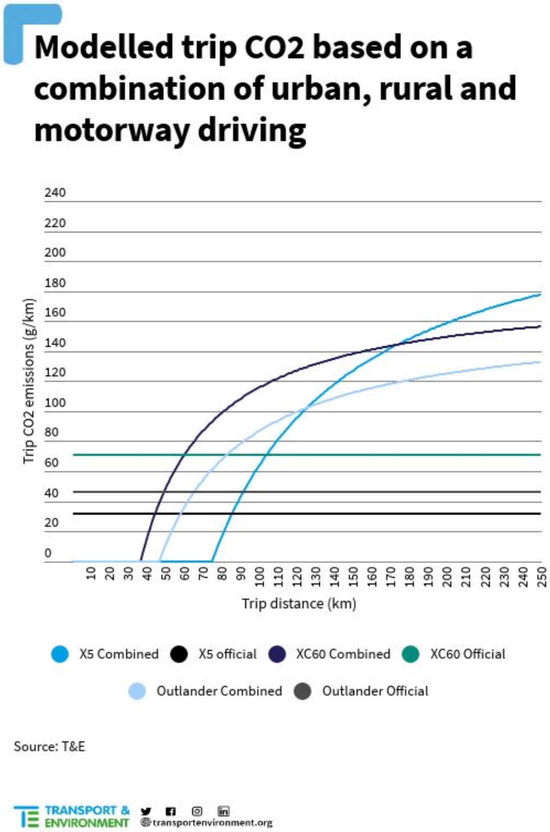
4.1.2 Modelled maximum trip distance for PHEVs to stay under type-approval limits during combined and motorway driving conditions

The trip distance dependent emissions presented above are based on the CO2 consumption and distance driven on each specific test. However, in practice, this means that CO2 emissions are not necessarily representative of all driving conditions (urban, rural, motorway). For the X5, for example, during the EV-predominant test, the ICE switched on during the motorway part of the test and as such the CO2 emissions measured on this test are largely representative of motorway driving only.

Therefore, in order to assess how total trip CO2 emissions evolve on average for each PHEV tested, CO2 emissions have to be modelled based on the CO2 emissions of several tests (Figure 11). Combined emission (for each PHEV) models evolution of per km CO2 emissions starting under EV-predominant operation until ICE is switching on and continuing in ICE-only operation after this point. This is calculated by combining the EV-only distance measured during the EV-predominant test followed by the average CO2 emissions measured during the ICE-mode test, both measured under mild/moderate RDE driving conditions[44]. For example for the X5 this combines a zero emission period of 75km, followed by CO2 emissions of 254g/km, (which covers the CO2 measured during urban, rural and motorway driving conditions).

Similarly, motorway driving models how trip CO2 emissions evolve starting with a fully charged battery in EV-predominant mode, followed by ICE-mode operation however, this time with the majority of the driving taking place on the motorway (figure 12). This combines the EV-only range measured during the reverse order test (which essentially measures the cars' EV-only range under motorway driving conditions) and the average motorway only emissions measured on the ICE-mode test.

[44] CO2 emissions measured under ICE-mode operation are a suitable proxy for average emissions measured when the battery is depleted as only a minimal amount of battery discharge occurred for the X5 and XC60 once the ICE engine is turned one. For the Outlander electric consumption continued after ignition of the ICE, however due to the wiring setup it is impossible to tell if this came from the engine or the battery. As this mode of operation also took place on the ICE-mode test there should not be a large difference in CO2 emissions as can be attested by the small difference in motorway emissions measured during the EV-only and ICE-mode tests.



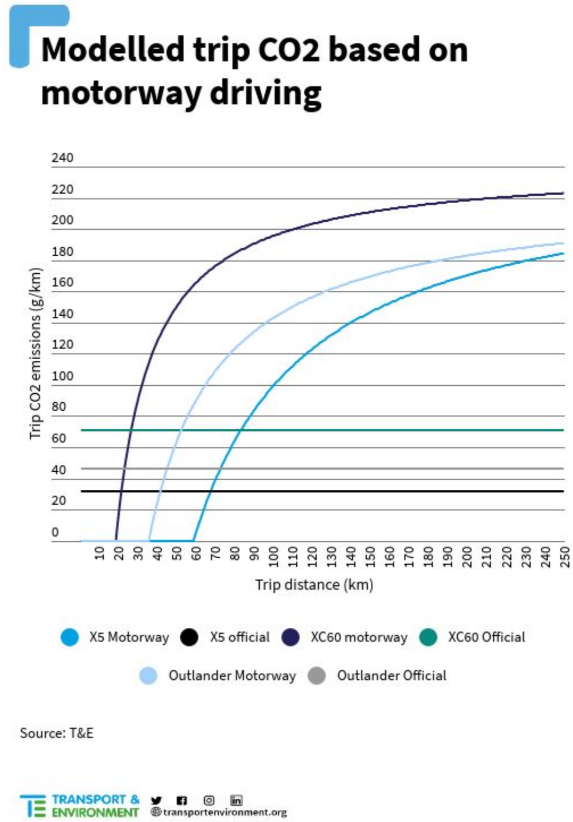


Figure 11 and 12: Modelled CO2 emissions of the X5, XC60 and Outlander as a function of distance, starting in EV-only operation under combined (urban, rural and motorway) and motorway only driving.

The modelled results show that under combined driving conditions, on average, once the X5, XC60 and the Outlander switch from EV-only operation, they are able to only drive an estimated 11km, 23km and 19km, respectively, before total trip CO2 emissions exceed type-approval values. This means that on average the cars can drive an estimated 86km for the X5, 61km for the XC60 and 67km for the Outlander before exceeding their official WLTP values. This range decreases further under motorway driving conditions to an estimated 68km for the X5, 28km for the XC60 and 46km for the Outlander, predominantly due to the shorter EV-only range measured under these conditions.

4.2 Long PHEV trips result in high CO2 emissions

4.2.1 CO2 emissions of 100km and 200km trips

In general it is disappointing to see that for all three vehicles tested, both under measured and modelled conditions, the distance that these cars can drive before exceeding their official CO2 values is limited. This is especially concerning given that these cars are touted to be the best option for drivers, who want to reduce their CO2 emissions and fuel consumption, but need to drive long journeys and when considering passenger car fleet data, e.g. from Germany.

PHEV use data[45] as presented in Table 1, shows that in Germany PHEVs can spend a large share of their total annual mileage driving long distances. Particularly large shares are reported for company PHEVs which can, on average, spend up to 47% of their annual mileage on daily trips over 100km and up to 25% on trips over 200km. These distances are much longer than the estimated compliance distance (C_D) of the three PHEV tested by T&E. This means that if driven on these long trips all three PHEVs would emit much higher CO2 than their type-approval values.

Results combining the trip length data from Germany and the modelling of CO2 emissions (under urban, rural and motorway driving) for the three PHEVs tested, undertaken in section 4.1.2 are presented in Table 1. These show that trips above 100km - which account for up to 47% of km's driven by company PHEVs in Germany and around 19% of km's driven by private PHEVs - result in estimated CO2 emissions of at least 1.6-3.1 times the official values. For trips of 200km or more, CO2 emissions are estimated to be at least 2.1-5.3 times the official values.

This shows that PHEVs, particularly those with a short electric range, are probably not the right choice for users needing to drive long distances (e.g. on motorways) as they will largely be unable to access the advertised CO2 emissions and fuel savings, unless long journeys are interspersed with regular charging. The much higher real world CO2 emissions of PHEVs which are largely driven in this manner mean that they wrongly allow manufacturer's to benefit from super credits (for those PHEVs whose emissions are less than 50g/km) as well as lower CO2 emissions that OEMs accrue towards their fleet-wide targets, as in practice they do not achieve this performance on the road. This essentially undermines the effectiveness of the CO2 regulation, further discussed in section 6.

[45] Obtained from Voltastats.net and the German mobility Panel dataset (MOP 2010) as published in ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

Source	Sample size	Mean share of annual mileage above 100km daily	Mean share of annual mileage above 200km daily
2010 German Mobility Panel : Private cars	5812	19%	8%
2010 German Mobility Panel: Company cars	212	47%	25%

	CO2 emissions of trips above 100km (g/km)	Compared to official WLTP value	CO2 emissions of trips above 200km (g/km)	Compared to official WLTP value
X5 Combined	>64	x2.0	>159	x5.0
X5 Motorway	>99	x3.1	>170	x5.3
XC60 Combined	>116	x1.6	>150	x2.1
XC60 Motorway	>195	x2.7	>218	x3.1
Outlander Combined	>87	x1.9	>125	x2.7
Motorway Combined	>143	x3.1	>183	x4.0

Source: T&E. 2010 German Mobility Panel data as reported in ICCT/ Fraunhofer Institute (2020) Real-world usage of plug-in hybrid electric vehicles.

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Table 1: Long distance trip CO2 emissions of the X5, XC60 and Outlander based on modeled emissions (fig. 11).Daily trip data of German users as compiled by ICCT/Fraunhofer Institute from the German Mobility Panel dataset (MOP 2010)[46].

[46] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

4.2.2 Required EV-only range to stay below type-approval CO2 emissions on longer trips

In reality, for those consumers who undertake long distance trips regularly and only charge the battery once per trip, the real world EV-only range of each vehicle has to be greatly increased for the trip CO2 emissions to stay below official values and for the PHEVs to be a credible low emission alternative to conventional engines.

Figure 13 presents the estimated necessary EV-only range for the three tested PHEVs if they are to be driven in EV-only (zero-emission) mode as far as possible and while still emitting below type-approval CO2 values under mild/moderate driving conditions. These are calculated based on the emissions measured during the ICE-mode test. In the case of the X5 an additional curve takes into account the additional km's that could be driven under EV-only operation based on the battery charging during the ICE-mode test. This is calculated based on the amount of battery charging which took place during the ICE-mode test (65 Wh/km), the average electrical consumption during EV-only operation (263Wh/km) during the EV predominant test and the distance driven in ICE-mode operation as a share of the total trip.

The XC60 requires the smallest EV-only range predominantly due to the high type-approval CO2 emissions of this car (71g/km). However, the car still requires a battery capable of supplying an EV-only range of approximately 61km for an 100km trip, 123km for a 200km trip and 153km for a 250km trip. For the Outlander this is increased to 72km (100km trip), 144km (200km trip) and 179km (250km trip). For the X5 this is further increased to 87km (100km trip), 174km (200km trip), 219km (250km trip), largely due to the high ICE-mode emissions (254g/km). Even when taking into account the additional distance that can be driven due to the battery charging on the ICE-mode test, the necessary EV-only range of the X5 is still the highest of the three tested PHEVs at 84km on a 100km trip, 169km (200km trip) and 211km on an 250km trip.

In reality this means that in order for PHEVs which predominantly or regularly drive long distances to come close to their advertised CO2 emission values, the manufacturers need to significantly increase the real world EV-only range of the vehicles.

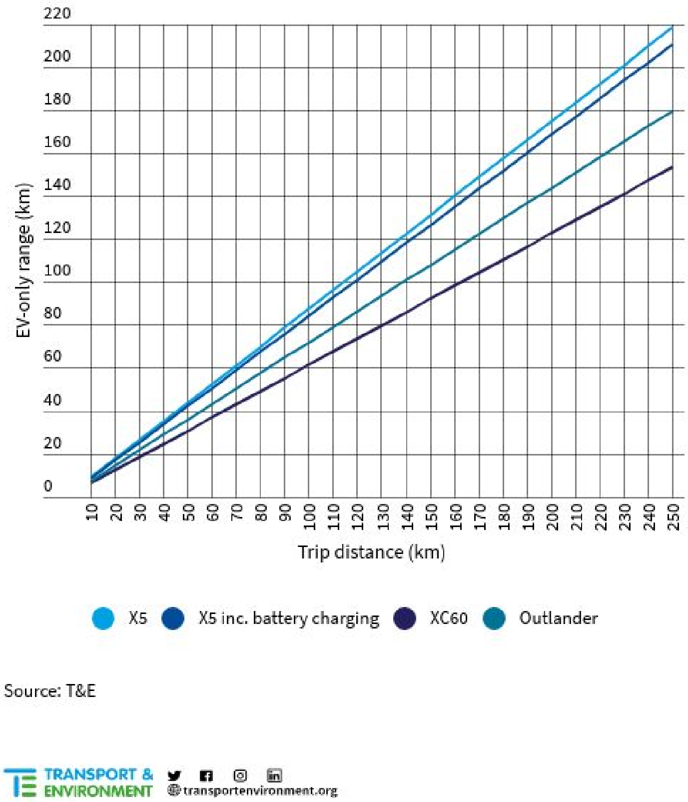

Figure 13: The estimated EV-only range necessary for each PHEV based on trip distance if the vehicle is to stay below it's WLTP type-approval CO2 emissions when starting the trip in EV-only (zero emissions operation)mode.

4.3 Comparison of on-road CO2 emissions with type-approval values

4.3.1 On-road and type-approval CO2 savings of PHEVs as measured on tests.

There is a certain CO2 saving per km that is expected from a PHEV based on the PHEVs low official emission values. In effect, the expected CO2 saving is equivalent to the difference between the WLTP charge sustaining (or ICE-only) emissions and final WLTP weighted and combined value. A comparison of the average CO2 savings expected and those actually achieved in the EV-predominant test are presented in Figure 14. Average type-approval CO2 savings were calculated by subtracting the type-approval (weighted combined) WLTP CO2 emissions from the charge sustaining WLTP CO2 emissions. For the real-world CO2 savings achieved in this test programme, the savings were calculated by subtracting the EV-predominant test emissions from the ICE-mode test emissions. As WLTP charge sustaining emissions are not included in the PHEVs certificate of conformity and Mitsubishi failed to provide this data for the Outlander upon request from EA , an analysis of the Outlander unfortunately could not be included here.

Given that CO2 savings are dependant on the total trip distance driven, and the fact that the mild/moderate RDE trip distance (92 km) was significantly higher than the real world EV-only range for all but the X5, the CO2 savings achieved on this test for the XC60 and Outlander were much lower than what could be expected based on official data. Even under mild/moderate operation the XC60 and the Outlander fall far short of the anticipated CO2 savings, achieving just over half of the expected value.

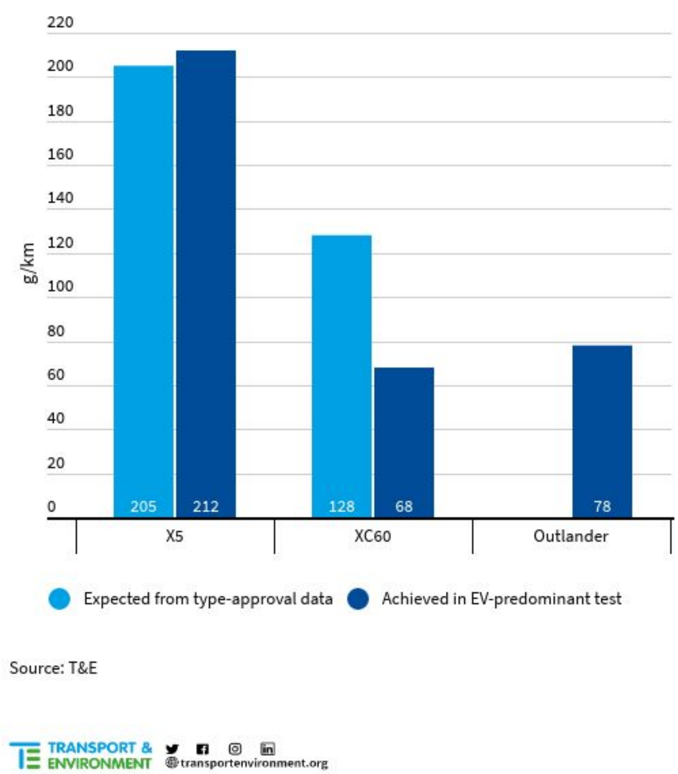

Figure 14: The expected CO2 savings per km from the three tested PHEVs based on type-approval data and those actually achieved on the EV-predominant test.

The CO2 savings achieved during the EV-predominant test were slightly higher (6.7g/km) for the X5 than expected from official data. Contrarily, the savings of the XC60 and Outlander were almost half of what is expected based on official data. This indicates that for longer trip distances as were tested during this testing programme only PHEVs with a high EV-only range are likely to achieve CO2 savings comparable to those expected from official figures.

4.3.2 CO2 emissions of PHEV vs. equivalent conventional cars

Figure 15, compares the official WLTP charge sustaining (CS) CO2 emission of the PHEVs tested by T&E and the WLTP CO2 emissions of comparable ICE models. The ICE CO2 emissions compared here are 179-249g/km in the case of BMW[47], 158-181g/km for Volvo[48] and 196g/km for the Mitsubishi[49].

[47] The Xdrive30dxline, Xdrive40dxline and Xdrive40ixline were used as a comparison for the X5. Source: BMW X5 Brochure. August 2020. Available upon request.

[48] The T6 AWD(B4204T29) and D(4204T23) model year 2018-2019 late were used as a comparison for the PHEV XC60. Obtained from the respective car manual available on the volvo website.

[49] Compared to the Mitsubishi Outlander 2.0L petrol 2020 model year, CO2 emissions obtained from Mitsubishi website.

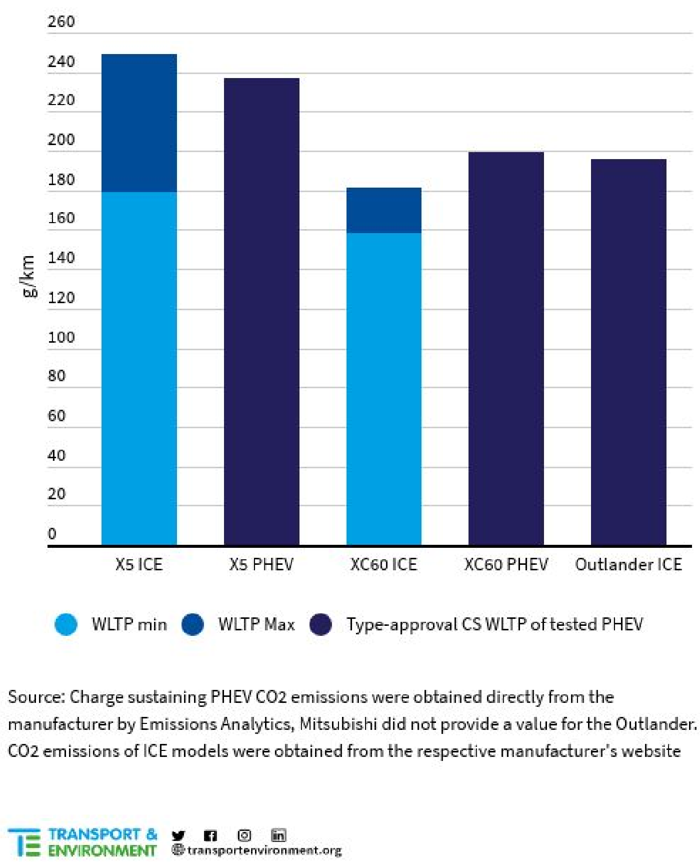

Figure 15: Comparison of WLTP charge sustaining emissions of the three tested PHEVs and those of comparable conventional ICE models[50].

As can be seen in the above figure, WLTP charge sustaining CO2 emissions of PHEV models are comparable or higher than similar ICE models. The largest gap between CO2 emissions exists for the X5 (237g/km CS emissions) when compared to the diesel version of the car: a minimum of 22g/km of additional CO2 is emitted and in the worst case up to 55g/km. When compared to the petrol version this specific X5 falls into the middle of the WLTP range (231-249g/km). The gap for the XC60 (199g/km CS emissions) is comparable at 17-41g/km depending on the vehicle specification and model year. Admittedly, the XC60 PHEV tested is designed with greater vehicle

[50] Again the Outlander charge sustaining emissions are missing as they were not provided by Mitsubishi upon request from EA.

performance in mind than conventional XC60 models, so CO2 emissions are not directly comparable. Overall, the PHEV charge sustaining mode emissions are higher for the XC60 compared to the highest CO2 emissions reported for a comparable ICE model. This is most likely due to the additional weight of the PHEV technology such as the battery, electric motor etc. This means that when driven in ICE-only mode - i.e. on an empty battery - the CO2 emissions of the PHEVs tested are often worse than the comparable conventional cars, or the vehicles they are designed to replace.

4.4. CO2 emissions in charging mode: an inefficient way to charge the battery

Most PHEVs on the market today are equipped with a driver selectable battery charging mode. During T&E's tests the highest CO2 emissions and fuel consumption for all three vehicles were measured during this specific mode due to the high engine load required for charging the battery. In the future, the potential rise of so called "geo-fenced" zones in urban areas, where PHEVs are required to drive in EV-only (zero emission mode), could increase the use of this mode in order to ensure that the battery has sufficient charge to operate within the geo-fenced area. The additional CO2 emissions, and the efficiency of charging in this manner, compared to charging directly from the grid are assessed in this section.

4.4.1 Up to an additional 12kg of CO2 emitted when charging the battery

The extra CO2 emissions required to charge the HV battery can be estimated by comparing the CO2 emissions between the ICE-mode and the charging mode, as both tests were driven on the same RDE compliant route.

Over the 91km test route, charging of the battery by the engine caused additional CO2 emissions of 12kg (131g/km) for the X5, 5.3kg (58g/km) for the XC60 and 4.8kg (53g/km) for the Outlander. For the X5 and the Outlander the additional CO2 required for battery charging alone exceeded the cars WLTP type-approval CO2 emissions, in the case of the X5 by over four times. In total, the CO2 emissions of the X5 in charging mode increased by over 50% compared to driving in ICE-mode, significantly more than for the XC60 and the Outlander. The larger increase in CO2 emissions can most likely be attributed to the much larger 24kWh battery compared to smaller batteries fitted to the XC60 (10.4kWh) and the Outlander (13.8kWh), requiring much more electric charge to be provided by the engine. However, for all three cars tested it is clear that battery charging is a very CO_2 intensive operation given that CO_2 emissions increase by more than 50g/km for all three vehicles tested.

4.4.2 Charging the high voltage battery using the engine is less efficient than charging from the grid

Due to the powertrain architecture of the X5 and the position of the battery clamp (used to measure electrical consumption during this testing programme) it was possible to measure the exact increase in the state of charge of the high voltage battery during the charging mode test, equal to 17.22 kWh. This was not possible to measure for the XC60 or Outlander. Combining this with the increase in CO_2 emission calculated in the previous section can be used to estimate the CO_2/kWh required to charge the high-voltage battery and compare this to the CO_2 intensity of charging the battery externally using the grid.

Taking into account the battery charging that took place during the ICE-mode test of 5.94kWh and assuming that the majority of battery charging both on the ICE-mode and Charging-mode test occurred from the ICE engine (and not regenerative braking), would mean that the extra 12kg of CO_2 emitted by the vehicle on the battery charging test resulted in a net increase of the state of charge of the battery by 11.28 kWh. Equal to CO_2 emissions of 1061g/kWh. This is close to the 935g/kWh reported by the European Commission's Joint Research Center based on RDE testing of a Euro 6 PHEV[51].

When this is compared to the CO_2 emitted from charging the battery from the electricity mains across EU Member States (figure. 16), based on 2020 lifecycle carbon intensity as calculated in T&E's 2020 report[52], it is apparent that charging the battery using the ICE is highly inefficient. When compared to the EU average, charging using the ICE instead of the mains emits between two to three times more CO_2 and in the case of e.g. Sweden (lowest carbon intensity in the EU) - where many Volvo PHEVs are sold - results in 15 times higher CO_2 emissions. As the EU electricity grid decarbonises further within the next decade, with forecasts expecting a decrease from an EU average intensity of 271gCO_2e/kWh in 2020 to 234gCO_2e/kWh in 2025 and 165gCO_2e/kWh in 2030, the gap between charging using the mains and the ICE will grow. As such, it is questionable whether this mode is in any way justifiable.

[51] JRC. (2019) On-road emissions and energy efficient assessment of a plug-hybrid electric vehicle.
[52] T&E. (2020) How clean are electric cars? T&E's analysis of electric car lifecycle CO2 emissions. 5% transport and distribution and 5% charger and battery lossed applied.

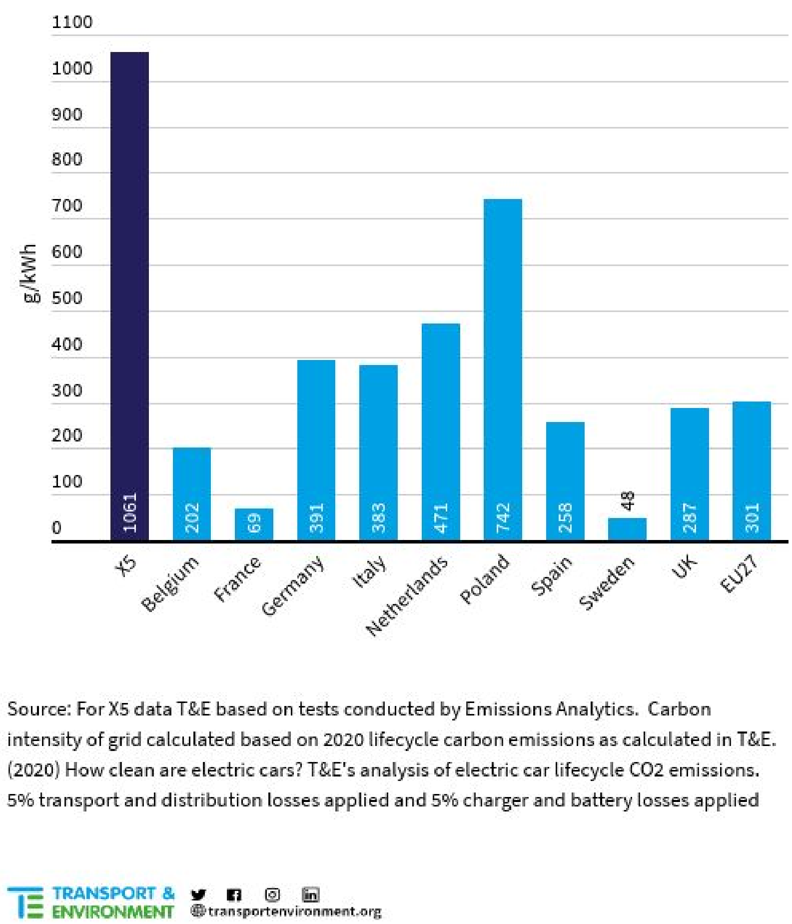

Figure 16: Comparison of the carbon intensity of charging the battery of the X5 using the internal combustion engine or the mains across Europe.

5. Real world usage of PHEVs & compliance with Car CO2 standards

While sections 3 and 4 of this report analysed test data from the three PHEV's, on the basis of individual trips, this section analyses the average - i.e. lifetime use rather than individual trip - CO2 emissions and fuel consumption of the three PHEVs based on real world PHEV usage data and compares these to official values.

5.1. Differences between type-approval and real world PHEV values

It is well known that there exists a large gap between official CO2 emission and fuel consumption values of PHEVs and their real world performance. Data compiled by T&E in September, from various databases (Table 2)[53], shows a divergence of between 221-306%, indicating that the current type-approval procedure for PHEVs greatly underestimates the CO2 emissions and fuel consumption of PHEVs. This is especially the case when considering that at its worst, the old NEDC test (which was unrepresentative and therefore replaced by the imperfect but better WLTP test) resulted in gap as high as 42% between real world and NEDC type-approval figures for conventional cars[54], yet this is still much lower than the current gap reported for PHEVs.

Source	Gap
Netherlands Travel Card data: 2017 ICCT Lab to Road report	242%
Netherlands Cleaner Car Contracts: 2017 ICCT Lab to Road report	270%
Spritmonitor data Germany	256%
Miles Consultancy data UK	281%
Fisches-Auto-France	294%
Netherlands Travel Card data: 2018 ICCT Lab to Road report	256%
AutoCentrum Poland	306%
Netherlands Travel Card date: 2019 ICCT Lab to Road report	221%

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Table 2: Reported gap between test and real world CO2 emissions of PHEV users.

The gap for PHEVs is much larger than for conventional cars, because for conventional cars the gap arises only from the difference between CO2 emissions/fuel consumption measured on the WLTP (or prior to 2017 on the NEDC) test cycle and what is measured on the road. However, for PHEVs an

[53] T&E. (2020) UK briefing: The plug-in hybrid con.

[54] T&E. (2018) Ending the cheating and collusion: Using real-world CO2 measurements within the post-2020 CO2 standards.

additional gap arises due to discrepancies between the regulatory assumptions on the share of EV and ICE km's driven by PHEVs, compared to real world operation of these vehicles.

The EU PHEV type-approval procedures (NEDC and WLTP) relies heavily on the assumption that the longer the electric range of a PHEV , the more likely it is that the car will be driven in a charge depleting mode (such as EV-predominant or hybrid operation) which uses the battery to at least partially power the car and results in lower CO_2 emissions and fuel consumption.

5.1.1. Type-approval of PHEVs and unrealistic utility factors

In order to use this assumption for regulatory purposes the Commission developed the concept of so called 'utility factors' (UF) which describe the relationship between the electric range of PHEVs [55] and the share of driving in EV mode. Under the WLTP test procedure the UF of the vehicle is determined based on the amount of kilometers that the PHEV can drive, starting with a full battery, under charge depleting operation (EV-predominant mode) before the battery is fully depleted. Then WLTP CO_2 emissions and fuel consumption as measured under charge sustaining (ICE-only mode) and charge depleting (EV-predominant mode) operation are separated into each phase of the WLTP test (low, medium, high, extra-high) and combined using the utility factor to give the final results using the formula below:

$$C = UF \times C1 + (1 - UF) \times C2$$

Where:
C = weighted fuel consumption (l/100km) or weighted CO_2 emissions (g/km)
C1 = fuel consumption (l/100km) or CO_2 emissions (g/km) in charge-depleting mode
C2 = fuel consumption (l/100km) CO_2 emissions (g/km) in charge-sustaining (CS) mode
UF=Utility factor

The utility factors assumed by the New European Drive Cycle (NEDC; in use for type-approval prior to September 2017, but still used for CO_2 compliance with the 2020/21 targets) and the World harmonised Light-duty Test Procedure (WLTP, in use since 2017) for a given EV-only range are presented in figure 17. As can be seen both utility factor curves are rather generous, with the utility factor increasing particularly rapidly for a type-approval electric range of between 0-30km.

[55] As determined at on a regulatory laboratory based cycle,

For example, for a car with a 30km electric range, it is assumed that around 50% of driven kilometers are electric (both under the NEDC and WLTP type-approval procedures).

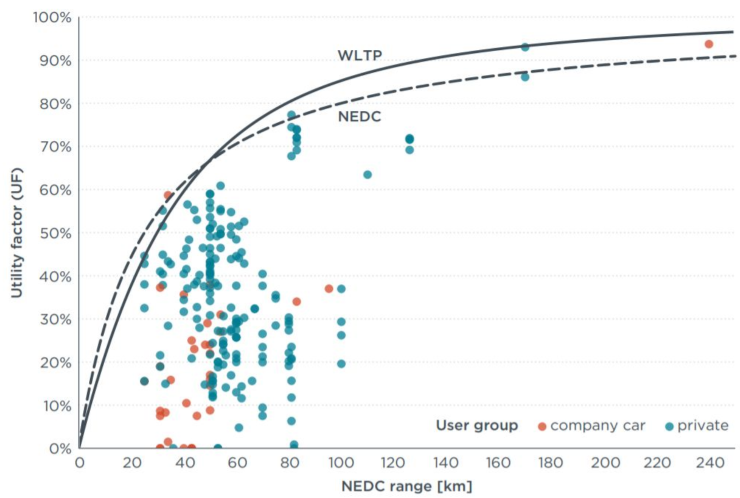

Figure 17: Assumed type-approval WLTP and NEDC utility factors[56]

This scaling of CO2 emissions and fuel consumption by a UF can drastically reduce the final type-approval values. For example the X5's WLTP charge sustaining (ICE-only) emissions are reported as 237g/km, but the final emissions after application of the UF are reported as 32g/km, a reduction of 87%.

The real-world data on PHEV usage recently published by the ICCT/ Fraunhofer Institute suggests that in reality a much smaller share of real world PHEV kilometers are electric than the NEDC/WLTP regulations assume. The study reported that while the average type-approval NEDC UF for privately owned PHEVs in Germany was 65%, the average real world UF was much lower at 43%. In Norway the official average UF was 64% compared to 53%.

The gap reported is even bigger for company cars, which is particularly conconcerning given that in 2019, company car sales accounted for 72% of PHEVs purchased in the EU[57]. The real world UF

[56]Source ICCT. (2020) [Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions](#).

[57] Dataforce on behalf of T&E. Dateforce. (2020) [Transport Environment: company car report](#)

for company cars reported by ICCT/Fraunhofer is only approximately a third of the official NEDC values; 62% vs. 18% in Germany and 65% vs. 24% in the Netherlands. These figures are similar to Stroohm Belgian company PHEV usage data reported by founder Bart Massin, who reports that for PHEVs within its fleet only around 8% of all kilometers driven are electric. This is mainly due to poor user charging behaviour; 55% of the reported Belgian PHEVs do not charge their batteries on a weekly basis[58]. Similarly, The Miles Consultancy in the UK has reported that there are examples of company car users returning their vehicles with the charge cables still unwrapped, having never charged their PHEV[59]In practice this data suggests that company PHEVs are predominantly driven on a combustion engine, more than 80% of the time in Germany, 76% in the Netherlands and as much as 92% in Belgium.

Using PHEV usage data from Germany the author's of the study modelled real world utility factors as a function of NEDC range for both company and private cars and found them to be much lower than both NEDC and WLTP utility factors regardless of the electric range of the vehicles (Figure 18). For a privately owned PHEV with 30km of range, only 31% of driving occurs in electric mode and only 11% for a company PHEV[60], compared to around 50% assumed under WLTP and NEDC type-approval procedures.

[58] Stroohm. Bart Massim. (29th October 2020) To plug or not to plug-in (hybrid).
[59] PHEVs Hollick. P. Miles consultancy. (2018) Fleets and the company car business urgently need to change their approach to plug-in hybrids.
[60] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

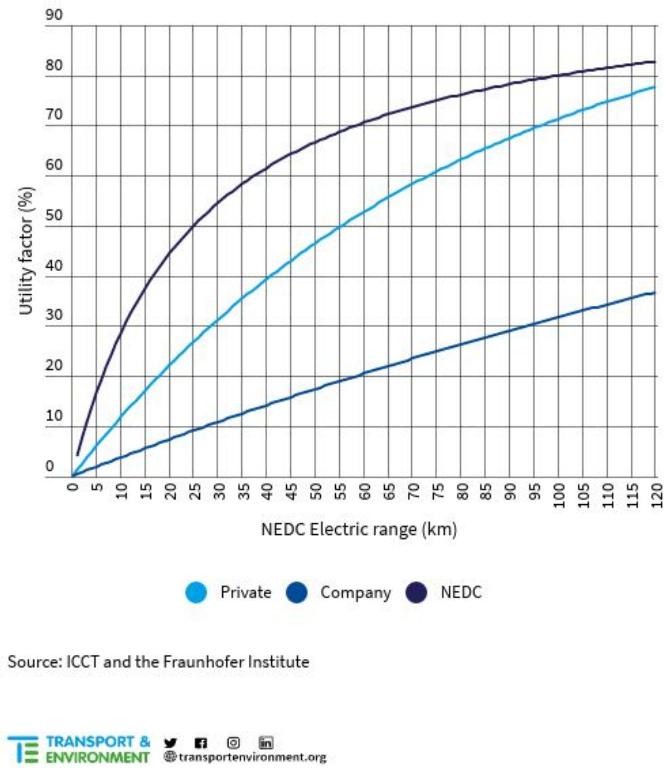

Figure 18: Assumed type-approval NEDC utility factors and private and company utility factors based on German usage data as calculated by ICCT/Fraunhofer Institute. Company UF are weighted and the i3REX is excluded from the sample as it is no longer available for sale but has an appreciable effect on the UF[61].

5.2 Estimating more realistic utility factors and CO2 emissions of the tested PHEVs

Overly optimistic assumptions on the real world usage of PHEVs can cause a large gap between real world and type-approval values. Since NEDC CO2 values are used for calculating compliance with EU fleet average CO2 targets, unrepresentative PHEV CO2 emissions can undermine the

[61] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions and personal communication with Patrick Plötz from the Fraunhofer Institute.

integrity of the regulation. This section uses the real-world NEDC UF for private and company cars from the ICCT/Fraunhofer study (fig. 18) to estimate the real-world utility factors of the three vehicles tested by T&E. These more realistic NEDC utility factors are then used to calculate more realistic NEDC CO2 emissions for the three vehicles tested.

5.2.1 More realistic utility factors of the three tested PHEVs

The NEDC electric range of the three PHEVs was obtained from the vehicles' certificate of conformity. This, along with the assumed type-approval NEDC UF's and more realistic private and company UF (based on UF curves determined by ICCT/Fraunhofer, fig. 18), are presented in table 3[62].

	X5	XC60	Outlander
NEDC electric range (km)	94	42	54
Assumed NEDC UF (%)	79	63	68
UF private (%)	69	41	49
Gap Private UF vs. NEDC UF(%)	-13	-35	-28
UF Company (%)	30	15	19
Gap Company UF vs NEDC UF (%)	-62	-76	-72

Source: T&E

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Table 3: UF Assumed at NEDC type-approval and real world utility factors for the three PHEVs tested (calculated from utility factor curves provided by ICCT/Fraunhofer Institute based on German usage data, fig.18).

[62] For company cars the UF is weighted based on the sample with the i3REX excluded from the sample as this car is no longer available for sale and the car is not representative of other PHEVs on sale today due to the large battery and small engine fitted to the vehicle, which is used as a range extender only.

As can be seen, the real world UF's, for the three cars tested by T&E, calculated based on German usage data are much lower than the official UF. For privately used PHEV's the gap stands at between 13-35%, meaning that in the real world privately owned PHEVs are driven under EV operation up to around a third less than the regulation assumes. The gap for company cars is much larger, for the X5 increasing to 62%, for the XC60 to 76% and the Outlander 72%. This means that under real world company car usage the Outlander and XC60 are likely to only be driven electrically around a fifth of the time. For the X5 this is slightly higher at around a third of the time.

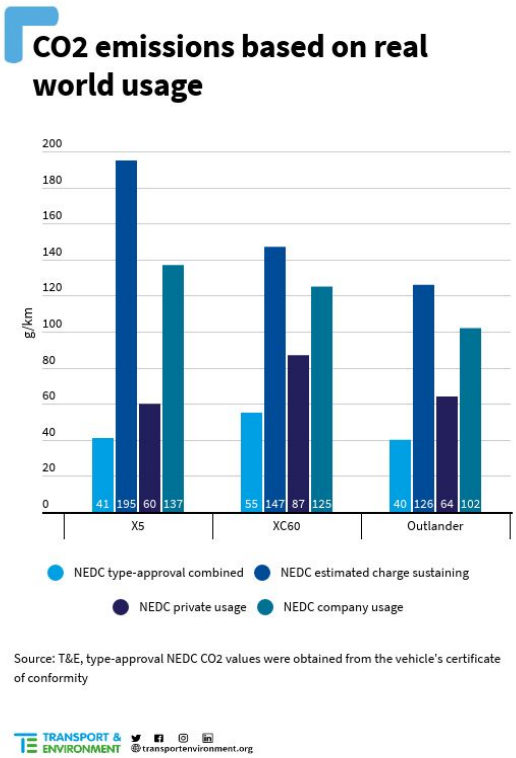
The much larger discrepancy for company cars compared to private cars can be partially attributed to the longer average trip length and higher annual mileage of company cars; due to the relatively low real world electric range of PHEVs a smaller share of total km's is electrified. Additionally, company car users in Germany may be provided with a fuel card but may not be incentivized to charge or may not even have access to workplace charging[63], resulting in a large gap between how PHEVs are intended to be used and how they are used in practice today.

5.2.2 NEDC CO2 emissions of the three PHEVs based on realistic UF

More realistic NEDC CO2 emissions - and therefore fuel consumption - for the three tested PHEVs can be estimated by combining the private and company car UF calculated for each vehicle with the CO2 emissions measured on the NEDC test during charge sustaining (ICE-only operation)[64].

[63] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

[64] NEDC charge sustaining emissions or fuel consumption are not reported on the vehicle's certificate of conformity. As such, these were estimated using the following equation: (combined NEDC CO2 x (NEDC electric range + 25))/25. To calculate charge sustaining fuel consumption combined NEDC CO2 emissions were replaced by combined NEDC fuel consumption. 25 is the average distance drive in charge sustaining mode as assumed by UN-ECE R101. For the purpose of this calculation was assumed that the CO2 emissions in charge depleting operation were 0.



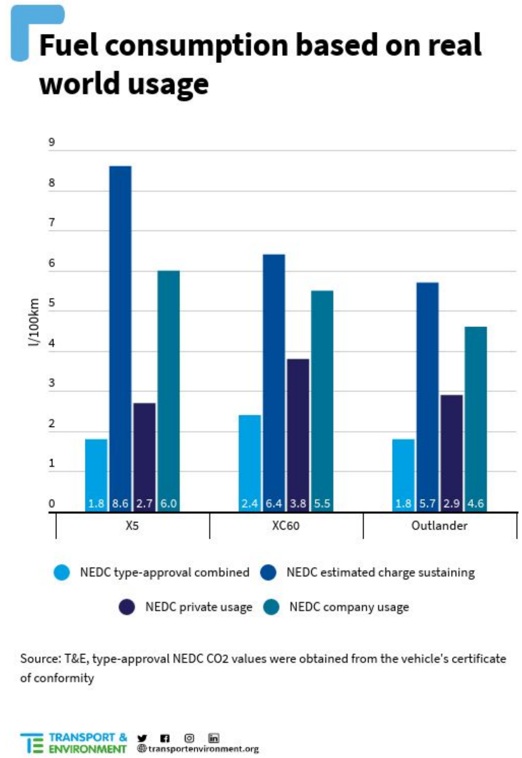


Figure 19 and 20: Real world CO2 emissions and fuel consumption of the three PHEVs tested calculated based on utility factors in Table 3.

As can be expected from the much lower real world UFs -i.e.much less electric driving - NEDC CO2 emissions and fuel consumption (based on German PHEV usage) are far in excess of the official figures. Despite having the highest electric range of all three PHEVs tested and therefore the highest UF, the X5's NEDC CO2 emissions and fuel consumption under private use were 50% higher than type-approval values, with a gap of 19g/km. When used as a company car they were over three times higher, resulting in a gap of 96g/km.

For the XC60 NEDC CO2 emissions and fuel consumption were 1.6 times higher when used as a company car with a gap of 32g/km. Under company car usage CO2 emissions and fuel consumption were 2.2 times higher with a gap of 70g/km. For the Outlander the NEDC CO2 emissions from private usage resulted in 1.6 times higher emissions (24g/km) increasing to 2.6 times (62g/km) under company usage.

These results show that both private and company use of these three vehicles results in NEDC CO2 emissions which are higher than 50g/km for all three cars. As 50g/km is the threshold for super credits and Zero and Low Emission Vehicle (ZLEV) credits, this suggests that none of these vehicles should be eligible for either scheme. Since the official NEDC CO2 figures of the X5 (41g/km) and the Outlander (40g/km) are less than 50g/km, the manufacturers of both PHEVs are unduly rewarded for their sales.

Despite the X5 having the longest electric range, its high charge sustaining (ICE-only) CO2 emissions mean that under company car usage the CO2 emissions and fuel consumption of this PHEV are higher than from the other two vehicles. This indicates that while the EV-only range of a vehicle is an important determinant of the real world CO2 emissions, high CO2 emissions during ICE-only operation can result in higher CO2 emissions than a vehicle with a much lower EV-range, higher than the Outlander and the XC60 in this case. As such, in order to reduce CO2 emissions from PHEVs it is insufficient to only increase their EV-only range as CO2 emissions/fuel consumption in ICE-only operation have such a large impact on final figures.

The above results show that there is a large gap between type-approval NEDC values and what the values should be based on real world usage, which undermines the integrity of the CO2 regulation by making it easier for car manufacturers to meet their fleet wide CO2 targets. However, for consumers, official CO2 and fuel consumption values of PHEVs are already determined on the updated WLTP cycle. This shift is not expected to appreciably reduce the gap between type-approval and real world values as utility factors not based on real world usage are still used in the WLTP test procedure. For the XC60 and Outlander this only results in an increase in CO2 emissions of 16g/km and 6g/km compared to the type-approval NEDC values. This is still lower than the private and company NEDC values determined for these cars.

In fact, for vehicles with a relatively long electric range[65], the shift to the WLTP test procedure can in some cases reduce type-approval CO2 emissions and fuel consumption. In the case of the X5 tested by T&E the shift reduced CO2 emissions from 41g/km to 32g/km, further increasing the gap between-real world and type-approval values. This occurs because for PHEV's with a longer

[65] Eder. A., Schutze. N., Rijnders. A., Riemersma. I., Steven. H., (2014) Development of European Utility Factor Curve for OVC-HEVs for WLTP.

electric range the WLTP test procedure assumes an even higher share electric usage than under NEDC . For example, it is assumed that a PHEV with a type-approval electric range of 80km spends almost 90% of its total mileage powered by the battery compared to around 80% under NEDC.

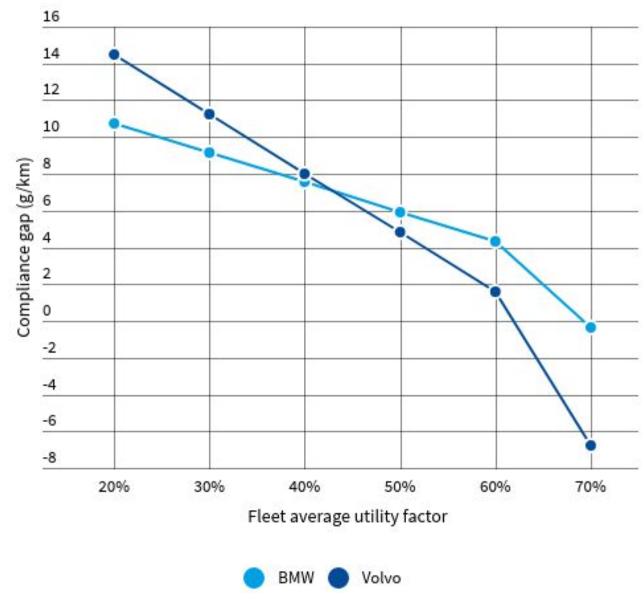
5.3 Effect of representative PHEV NEDC CO2 emissions on compliance with car CO2 standards

PHEVs are a key compliance strategy for many carmakers with the 2020/21 CO2 emission standards, including BMW and Volvo, two models of which were tested by T&E. The estimated fleet average CO2 target for BMW and Volvo in 2020 is 103g/km and 111g/km respectively. Based on forecast EV sales (largely PHEVs) of 14% for BMW and 26% for Volvo and projected compliance for 2020, both BMW and Volvo are expected to over-comply with their 2020 target: reaching 102g/km for BMW and 105g/km for Volvo[66]. However, the use of more realistic utility factors for calculating NEDC CO2 emissions of PHEVS can have a large impact on manufacturer fleet average CO2 emissions.

T&E modelled the impact that a fleet average UF of between 20-70% would have on the fleet average CO2 emissions of BMW and Volvo. Charge sustaining (ICE-only) NEDC emissions of BMW's and Volvo's PHEVs were obtained from the Electric Vehicle Database[67] and scaled by a 20-70% utility factor[68] in 10% intervals to obtain new NEDC values for the PHEVs. These were then imputed into T&E's CO2 model to calculate new fleet average CO2 emissions for Volvo and BMW based on fleet average utility factors of 20-70% (figure 22) . The gap between the calculated fleet average emissions and the CO2 target is presented in figure 21. The methodology followed is the same as reported in the 2020 T&E report Mission (almost) accomplished[69] with assumptions made regarding the CO2 emissions of PHEVs further described in Annex 3.

[66] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.
[67] https://ev-database.uk/. Accessed October 2020.
[68] As such it was assumed that no CO2 emissions occurred under charge depleting operation.
[69] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.

Most importantly the modelling shows that if the utility factor of official CO2 emissions was adjusted, then in order to meet their fleet average CO2 emissions targets both Volvo and BMW need a very high average UF. For BMW this is estimated at 70% - i.e. their PHEVs have to drive in electric mode 70% of the time - and for Volvo towards the lower end of 60-70%. This is much higher than reported real world UF's of 18-53%[70] , suggesting that in practice it is unlikely that PHEVs from Volvo or BMW are achieving these high UFs in the real world.



Source: T&E

Figure 21: Compliance gap for BMW and Volvo reaching their 2020 CO2 targets depending on PHEV fleet average utility factors.

Depending on the UF, the gap in CO2 compliance varies by between 10.8g/km and -0.4g/km for BMW and 14.5g/km and -6.7g/km for the Volvo. In a scenario where all PHEVs sold by BMW and Volvo in the EU had, on average, a UF of 20% - in line with the average company car UF

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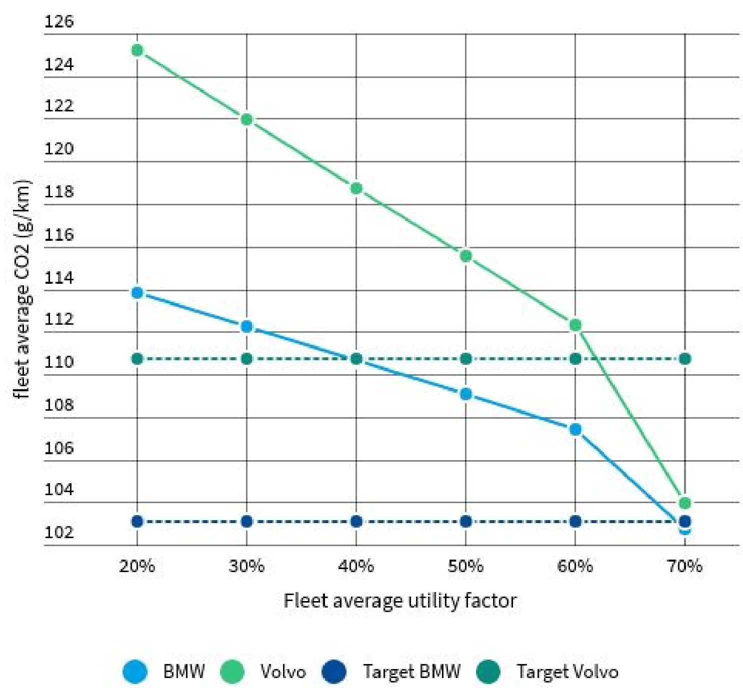
[70] From company and private PHEVs in Germany, the Netherlands and Norway. ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

reporterted by ICCT/Fraunhofer for the Germany and the Netherlands - fleet average CO2 emissions of BMW would be 114g/km, or 11g above their target/km. For Volvo the gap is even bigger at 14g due to the higher share of PHEV sales in the manufacturer fleet, with average fleet emissions increasing to 125g/km.

A higher fleet average UF of 40%, close to the 43% average utility for private cars reported by ICCT/Fraunhofer for Germany, would result in the fleet average CO2 emissions of 111g/km for BMW and 119g/km for Volvo. This is still 8g/km higher than their respective targets. Both OEM's need UFs of around 70% for their PHEVs to earn super credits. For both BMW and Volvo UFs of less than 60% result in PHEVs having emissions higher than 50g/km and therefore do not qualify for super credits.



Source: T&E

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Figure 22: Impact of PHEV fleet average utility factors (share of electric kilometers driven) on fleet average CO2 emissions of BMW and Volvo.

What this data shows is that unless BMW and Volvo are achieving fleet average utility factors of around 70% and between 60-70% respectively, then in practice the PHEVs that these two manufacturers are selling are 'compliance only' vehicles; used to reach the fleet average CO2 targets but failing to deliver the necessary CO2 savings in practice. This also shows that carmakers are unfairly benefiting from the 'supercredits' given for selling their PHEVs and in reality are far further from compliance when more representative CO2 emissions of their PHEV models are taken into account.

5.4 Impact of a more realistic UF on real world CO2 emissions

In order for the three PHEVs tested to emit less than 50g/km of CO2 or to reach their type-approval emission values, when starting in EV-only operation, the real world utility factors of all three vehicles have to be greatly increased. Figure 23 shows the CO2 emissions of each vehicle depending on the UF (which in this case is defined as the share of EV-only driving), based on the ICE-only emissions measured[71] during this testing programme under mild/moderate RDE conditions.

For the PHEVs to achieve emissions of less than 50g/km the real world, UF of each vehicle on average must be increased to around 80% for the X5, 73% for the XC60 and 69% for the Outlander. Similarly for the vehicles to reach their current type-approval figures the real world UFs must increase to 87% for the X5, 69% for the XC60 and 72% for the Outlander. An average UF which is any lower than these would result in CO2 emissions above type-approval values. Additionally, for vehicles that are regularly driven outside of mild/moderate driving conditions, the UF's would have to increase further to compensate for the lower EV-only range and potentially higher ICE CO2 emissions.

[71] This does not take into account CO2 emissions or fuel consumption that may occur in charge depleting operation. However, this is a reasonable approximation given that on the EV-predominant test only a minimal amount of battery was used by the X5 (0.44kWh) once the ICE turned on. For the XC60 where the contribution of battery or ICE engine could not be distinguished, but the combined use of both was 0.22kWh. For the Outlander the contribution of battery and engine could also not be distinguished. Once the ICE turned on, combined, 2.04KWh were used by the Outlander. However it should be noted that 7.19 kWh were also used during the ICE-mode test by the Outlander. As such the electricity used after ICE start on the EV-predominant test should also be reflected by the lower CO2 emissions on the ICE-mode test.

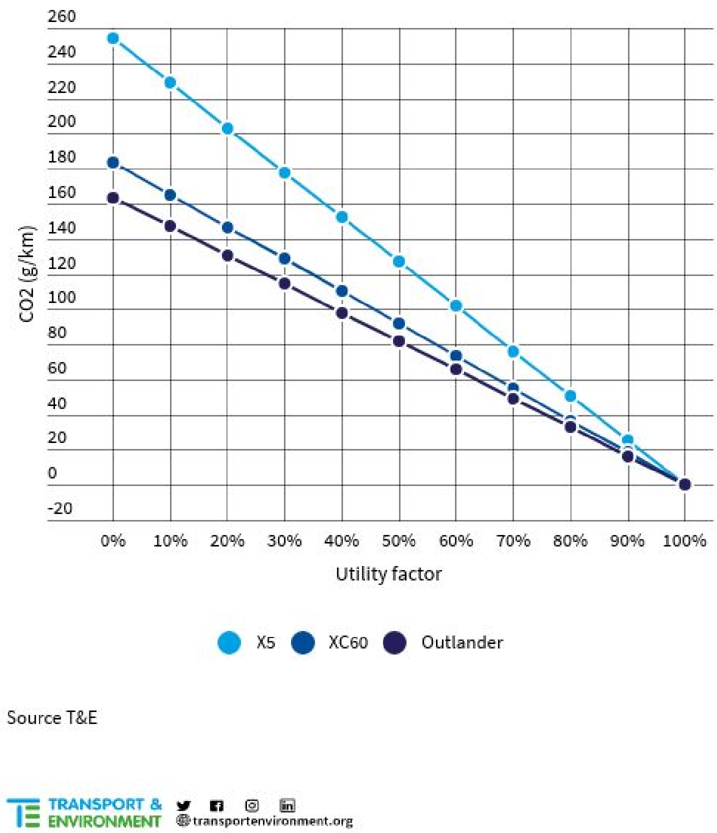

Figure 23: Real world CO2 emissions reliance on PHEV utility factor i.e. the share of electric km's that the PHEV drives in the real world.

6. Conclusions and Policy Recommendations

Overall the results of this testing programme show that for all but the X5 tested in EV-mode under mild/moderate conditions, CO_2 emissions and fuel consumption of the three PHEVs tested greatly exceeds the official type-approval values. When real world private and company use of these vehicles is considered, the cars fail to deliver the expected fuel consumption and CO2 savings. The resulting large gap between real world and type-approval values - much more than can be expected for conventional cars - means that PHEVs create more problems in the real-world than they solve. This is especially the case for company cars which benefit from generous purchase and tax incentives across many Member States but are rarely used in EV mode.

While it is true that if driven predominantly in EV-only mode, PHEVs can genuinely be low emission, car manufacturers have failed to design their PHEVs for such use. However, the poor design of PHEVs on sale today means that they are not. The current poor design and real world performance of PHEVs is a colossal failure of current laws and taxation policy and reform is far overdue. Europe needs to fix regulations both at EU and Member State level to require better performing PHEVs, as well as to incentivise drivers to charge more regularly. Regulatory focus has to shift to real world compliance. The following section discusses the improvements that manufacturer's need to make to their PHEVs, if PHEVs are to be part of the transition to zero emission mobility, as well as the policy recommendations which need to be implemented to close the regulatory loopholes surrounding PHEVs and deliver cars which are both better for consumers and the climate.

6.1 PHEVs should be designed to be used in zero emission mode

If PHEVs are to be part of the transition to ZE, carmakers need to step up their game and design PHEVs to be used in EV-only mode, which can actually deliver large CO2 and fuel economy savings in the real world. To achieve this, it is simply not enough to fit an electric motor and battery to an ICE car for regulatory and tax advantages and mark this as a job well done. To keep PHEVs in the game carmakers need to put their heads down and focus on substantially increasing the share of EV-only operation of their PHEVs. This means that they need to make it easy and attractive to use PHEVs predominantly in EV-only operation.

6.1.1.Manufacturers need to increase the EV-only range of their PHEVs under all driving conditions

Car manufacturers need to focus on vastly increasing the EV-range of their PHEVs in real-world driving conditions In practice manufacturers can achieve this through a number of measures, notably by increasing the size of the battery. Unfortunately, without regulatory or tax incentives it does not appear that average PHEV battery size will increase substantially within the next decade. The IHS Markit forecast of car production in Europe (Table 4)[72], acquired by T&E, forecasts that while between 2019-2027 BEV average battery capacity is expected to increase by 21kWh from 48 kWh to 69kWh, PHEV's average capacity will increase by a measly 3kWh, from 12kWh to 15 kWh. This indicates that if regulatory changes are not made there is going to be hardly any improvement in PHEVs for the foreseeable future.

T&E recommends that in order to drive an increase in the EV-only range of PHEVs, Member States should tie purchase and tax incentives to the EV-only range of a PHEV and for PHEVs to qualify they should have a minimum range of 80km.

Capacity (kWh)	2020	2021	2022	2023	2024	2025	2026	2027
PHEV	12	13	13	13	14	14	15	15
BEV	56	62	62	65	66	67	67	69

Source: IHS Markit light-duty vehicle production forecast, Europe

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Table 4: IHS Markit forecast of expected average battery capacity for PHEV and BEV vehicles between 2020 and 2027.

Additionally, in order to maximise the share of EV-driving, manufacturer's need to ensure that their PHEVs are capable of driving in zero- emission mode under all on-road driving conditions as is necessary for BEVs. This was not the case for the X5 or the XC60, which had to switch on the ICE when driving more dynamically (with greater acceleration and altitude gain). Similarly, even the Outlander manual[73] for the latest Outlander PHEV model advises owners that the engine will start automatically if the car has not been topped up with at least 15 litres of fuel in three months, forcing users to use the internal combustion engine. While this was not observed during the

[72] IHS Markit light-duty vehicle production forecast, Europe.
[73] Mitsubishi Motors. Outlander PHEV Owner's Manual: ENGLISH OGGE20E1. https://owners.mitsubishi-motors.co.uk/media/pdfs/owners-manuals/OGGE20E1.pdf. Accessed 28/20/2020.

testing programme, the manual also advises that the engine may start if the PHEV system is too hot/too cold, quick acceleration is applied or the air conditioning is operating.

Practically, this means that manufacturers need to fit more powerful electric motors and batteries that are capable of staying under EV-only operation under a wide range of driving conditions. Otherwise they need to limit the power (acceleration, top speed) available to the driver in order to maximise the share of EV- only driving.

However, T&E's analysis[74] shows that for PHEVs produced in the European Union in 2020, on average, the power of the electric motor is less than half - only 43% - of the power of the internal combustion engine. This indicates that the PHEVs sold on the market today are much closer to conventional combustion engined cars than battery electrics. More worryingly, this is not expected to improve in the future with the average power of the electric motor vs. ICE increasing by just 1% in 2025, to 44%. Additionally, large numbers of PHEVs are expected to be sold in 2025 with the electric power of just a tenth of the power of the ICE. If manufacturers want PHEVs to qualify as low emission then they need to ensure that they are designed to be operated as low emissions vehicles. Therefore they should fit electric motors which are just as powerful as the internal combustion engine to allow consumers to use the electric drive, and not the ICE, as much as possible.

[74] IHS Markit forecast data (July 2020 update). The power of the electric motor was calculated as the difference between the total power available to the vehicle and the power of the internal combustion engine. Electric and conventional power were then compared by analysing their ratio.

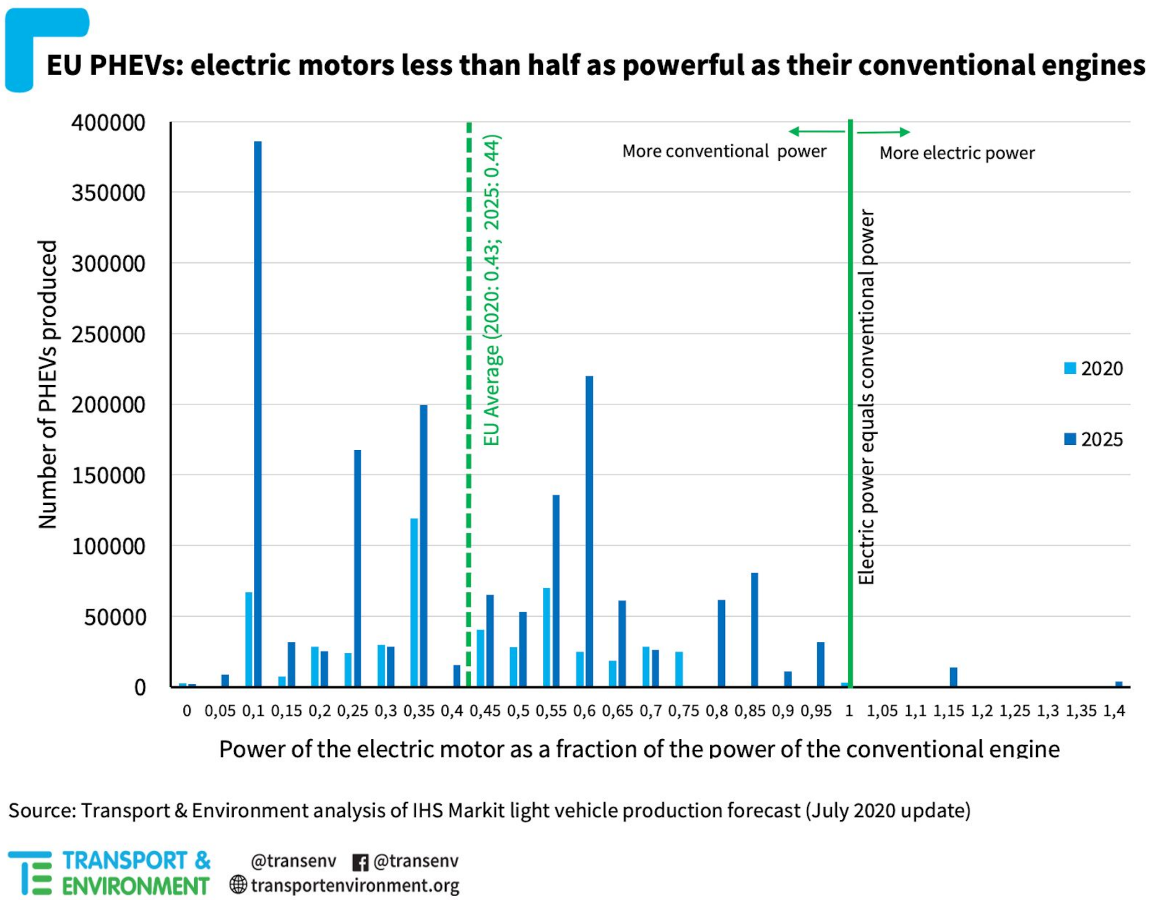

Figure 24: Ration of electric motor vs. internal combustion engine power from T&E's analysis of IHS Markit light vehicle production forecast (July 2020 update). At a ratio of 0.25 the EV-motor is 25% of the power of the ICE. At a ratio of 1 both have the same power. For ratio above 1 the EV-motor is more powerful than the ICE.

6.1.2 Manufacturers need to make it easy to charge their PHEVs

Regular charging and driving of PHEVs under EV operation is key to achieving low CO2 emissions and fuel consumption on the road. As such, manufacturers should make it as convenient, quick and easy as possible to charge their PHEVs. However, many PHEVs on sale today are not even fitted with fast charging technology which is more or less standard for BEVs.

This is a problem, as due to the small size of their batteries, charging on the go is essential for maximising the share of EV operation of PHEVs. Of the three cars tested only the Outlander was equipped with fast CHAdeMO DC charging allowing for a full charge in 32 minutes. However, it should be noted that the maximum charge speed was limited to 22kW, not the 55kW which can be supplied by the technology. Disappointingly, neither the XC60 or the X5 are fitted with fast DC charging technology. The fastest charging available for each vehicle is 3.7kW AC charging, requiring 7 hours to fully recharge the X5 and 3hours 15 minutes for the XC60, hardly suitable for re-charging during a brief stop.

If the EV-only use of PHEVs is to be maximised, these cars need to be capable of fast charging - for full battery in 30 min - which means manufacturers need to fit them with fast DC charging technology. **T&E recommends that manufacturers, as standard, fit all PHEVs with fast charging technology, at the minimum allowing the PHEVs to charge at a rate of 50kW per hour.**

6.1.3 Manufacturers need to reduce the CO2 emissions of these cars when the engine running

Manufacturers should also reduce the CO2 emissions of their PHEVs when under ICE-only operation as ICE emissions have a large impact on total PHEV CO2 emissions. When ICE emissions are particularly high they can outweigh the benefits of a long EV-only range:[75].

Carmakers should therefore reduce the fuel consumption of PHEVs under ICE and battery charging operation. Manufacturers should, therefore, apply better technology to the PHEV engines and powertrain to increase their efficiency and lower CO2 emissions. Limiting power of the ICE engine as well as the system as a whole (eg. acceleration) and reducing the size and weight of the vehicle should also help reduce the fuel consumptions and CO2 emissions.

Yet, manufacturers may find it difficult to reduce the size or weight of PHEVS as the majority of the growth in the PHEV market has been the sale of SUVs. In fact in 2019 the average mass of a PHEV was 1938kg, 39% heavier than an average conventional ICE[76]. This is hardly surprising given that the market share of SUV's has risen to a third from 7% in 2008[77] and manufacturers make a

[75] Based on German usage data.
[76] EEA. Monitoring of CO2 emissions from passenger cars-2019 provisional data.
[77] Historic SUV market share from ICCT's Pocketbook: http://eupocketbook.org/

hefty profit on the sale of these cars. Their market share is expected to further increase up to 40% by 2021[78]. However, the simple fact remains that once the battery is exhausted the ICE has to almost solely power the vehicle, and for a large SUV, which is heavier and has poorer aerodynamics, this inadvertently results in higher CO2 emissions and fuel consumption than a smaller car.

Measurement of real world fuel consumption and CO2 emissions of the EU PHEV fleet and using these for regulatory purposes should encourage manufacturers to reduce the CO2 emissions of their vehicles. The following section discusses this in further detail.

6.2. Cars CO2 regulation and the ZLEV benchmark

The Cars CO2 regulation is the driving force for reducing CO2 emissions from cars in the EU. It is also the main EU-wide measure to stimulate investments in, and supply of, zero and low emission vehicles, defined as those under 50g CO2/km (WLTP); so battery, fuel cell and plug-in hybrid cars.

However, the way in which PHEVs are credited in the current regulations allows carmakers to easily use sub-optimal models as a compliance strategy to hit their targets, and not focus on the real-world CO2 savings. First, the artificially low type-approval emissions of PHEVs helps carmakers reduce their fleet average CO2 emissions, making it easier for manufacturer's to comply with targets.

Second, manufacturers benefit from additional rewards from the sale of EVs, including PHEVs. Until 2022 PHEVs which emit less than 50g/km of CO2 benefit from generous 'supercredits', allowing each PHEV sold to be counted as more than 1 car, thereby greatly increasing the benefit and encouraging the sale of compliance PHEVs. While the 'supercredit' scheme ends in 2022, the post-2020 rules still rewards PHEVs. From 2025 the CO2 regulation includes a ZLEV (zero-and low-emission vehicles) benchmark that gives credits to electric and plug-in hybrid cars under 50g/km. Manufacturers who sell in excess of 15% ZLEV credits in 2025 and 35% in 2030 are able to reduce their CO2 fleet wide emission target by up to 5%. Whereas a battery or a fuel cell car - as zero CO2 emissions technology - gets 1 credit, plug-in hybrids emitting up to 50g CO2/km (WLTP) get smaller credits based on their type-approval CO2 performance. Unfortunately, the rules for calculating credits were weakened in favour of PHEVs during the final negotiations by adding an additional 0.7 multiplier, essentially rewarding PHEVs by around a third more, then they would

[78] T&E.(2019) Carmakers on course to meet CO2 targets despite years of pushing SUV sales.

otherwise be entitled to based on their CO2 emissions alone[79]. T&E has shown[80] that allowing PHEV's benefit from the 0.7 multiplier is by far the worst weakening of the regulation and may result in up to half of plug-in cars sold in 2025-2030 being pure compliance vehicles, or "fake electric".

The current regulatory design thus encourages car manufacturers to sell "compliance" PHEVs despite the vehicles failing to achieve low CO2 values in real world use, further increasing the gap between fleet average type-approval and real world emissions . For those manufacturers who are largely relying on PHEVs to meet targets - currently including Daimler, JLR, BMW and Ford - this is essentially a "get out of jail" card to avoid fines. This means that less real low and zero emission cars need to be sold, limiting the investment in and supply of these vehicles in the EU.

T&E recommends:

1. **As part of the 2021 Cars CO2 regulation review, remove the additional 0.7 ZLEV multiplier to ensure that PHEV's are not unduly rewarded.** This will also encourage the sale of longer EV-only range PHEVs as they would benefit more from the ZLEV creditting scheme.
2. **Remove the ZLEV benchmark - or any other additional rewards for selling EVs - after 2030.**
3. **Use more representative PHEVs CO2 emission values derived using the on-board fuel consumption meters and real-world utility factors for compliance with the EU fleet-wide CO2 emission targets.**

[79] T&E. (2020) Mission (almost) accomplished- Carmakers' race to meet the 2020/2021 CO2 targets, and the EU electric cars market.
[80] T&E. (2019) New car CO2 standards: Is the job of securing electric cars in Europe done?.

6.3. How On-board Fuel Consumption meters can help improve compliance

The type-approval of PHEVs, and in particular utility factors, fail to capture the real world usage of PHEV's, creating a huge gap between type-approval and real world CO2 emission and fuel consumption figures. This is largely due to the huge data gap on how PHEVS are really used and charged; at present there is no systematic collection of usage data from the EU PHEV fleet. In order to allow for the accurate quantification of the CO2 emissions impact of these cars, it is necessary to obtain and gather real world fuel/electrical consumption and CO2 emission data from the entire EU PHEV fleet.

As part of the 2019 CO2 Cars Regulation[81], the fitting of on-board fuel consumption meters (OBFCM) is compulsory for all cars from January 2021. These devices are intended to measure the mileage, fuel and electrical consumption of cars during real world operation, thereby also allowing for the calculation of real world CO2 emissions. The Commission is bound to collect and report data from OBFCM on a regular basis which is critical for monitoring the gap between real world and type-approval CO2 values of all vehicles. Regularly gathering detailed and complete OBFCM data from the entire EU PHEV fleet is the most promising solution to eliminating the knowledge gap on the real world use of these cars.

6.3.1 What & how OBFCM data needs to be collected from PHEVs

In order to finally answer the key question on what share of PHEV driving is actually conducted under EV operation, it is critical that OBFCM data is gathered for all OBFCM enabled PHEVs in the EU fleet.

As shown by T&E's testing, the fuel consumption and CO2 emissions of PHEVs vary greatly between different driving modes. As such it is imperative that the electrical and fuel consumption as well as the distance driven in each mode is collected by the OBFCM and transmitted to the Commission or the European Environmental Agency (EEA). In particular, the distance and electrical consumption in EV-only mode needs to be measured and collected in order to collect information on how often PHEVs are actually used in zero emissions mode.

[81] (EC) No 631/2019.

For the data to be useful for organisations such as T&E and consumers for assessing the gap between the real world and type approval performance of PHEVs **the CO2 emissions, fuel and electrical consumption as well as mileage of every PHEV model, in every PHEV driving mode, should be published annually by the Commission.** Additionally, the Commission should publish real world utility factors as well as the gap between type-approval and real world UFs. When reporting, the data should be aggregated by interpolation family, vehicle segment, fuel type, vehicle model, engine model, transmission type and registration year. If the data gathered from all of the OBFCM enabled EU fleet is aggregated by manufacturer only, it will be impossible for third parties or consumers to assess the real world performance of PHEVs or to compare the performance of different PHEV models.

In order to ensure that data is gathered from the entire EU PHEV fleet on a regular basis, **Over-The-Air (OTA) data transfer, where the OBFCM data is transmitted directly from the car to the Commission's or EEA's servers via secure mobile internet connection, must become the primary data collection pathway for all OBFCM enabled vehicles, as soon as possible and no later than 2023.** This is crucial as all other possible data transfer pathways including data collected during Periodic Technical Inspections (PTI) or gathered by car manufacturer's when cars come into be serviced, fail to gather the data on a regular basis from the entire OBFCM enabled EU fleet and therefore are only suitable for primary use in the short term until OTA technology is available on all new cars.

T&E suggests once OTA is available the data is gathered from OBFCM's on an annual basis and in the first year of registration - quarterly, so that the real world performance of new PHEV can be assessed promptly without having to wait in excess of a year for the data.

6.3.2. Use of OBFCM data for more accurate PHEV type-approval values

To ensure that the real world operation of PHEV's is accounted for in type-approval regulation, the EU should move away from the generic utility factors which are currently in use and have been shown not to be representative, towards UF calculated from OBFCM data. This would help ensure that type-approval fuel consumption and CO2 emissions figures better reflect real world usage of the different models.

At present, the same generic utility factors are used for the type-approval of all PHEVs in the EU. However, differences in car design, OEM customer base, as well as potential differences in customer usage (especially between private and company cars users), means that utility factors differ between manufacturer's as well as PHEV models[82]. Gathering OBFCM data from the entire EU PHEV fleet should allow for the calculation of manufacturer specific UFs which should further close the gap between type-approval and the real world.

T&E's recommendation therefore, that the EU moves away from using generic EU wide utility factors, towards manufacturer specific UF calculated on an annual basis from real-world data gathered from OBFCM's in the previous year.

Manufacturer specific UF would encourage manufacturers to design better PHEVs by rewarding manufacturer's who design the best in class cars, which are designed to be operated in EV-only mode as much as possible, and encourage their customers to charge their cars as much as possible. This should both reduce the gap between real world and type-approval CO2 emissions and fuel consumption as well as increase the share of electric kilometers driven by PHEVs in the EU. For the manufacturer specific UF to be as representative as possible they should be weighted based on the model specific utility factors calculated from OBFCM data and the share of the manufacturer's total PHEV sales.

6.3.3 Real-world emissions for consumer information on car labels

The 2019 cars CO2 regulation also requires the Commission to review the EU Car Labelling Directive[83] by the end of December 2020. The Car Labelling Directive is an important instrument that sets out the requirements for the labeling of cars at the point of sale. At present this includes the requirement to display information on the car's type-approval CO2 emissions and fuel consumption. However, for prospective buyers this provides very limited information on the real world performance of a PHEV due to the huge gap between type-approval and real world figures for these vehicles. Cear, accurate and detailed point of sale labelling of PHEV's in terms of their real-world performance under all modes of operation could be a powerful tool for educating customers on the fuel consumption and CO2 emission implications of running a PHEV in different driving modes. This will allow the consumer to better assess the true running costs of the vehicle based on their intended usage.

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[82] ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

[83] (EC) No 94/1999.

While the use of more representative UF's for type-approval will help close the gap between real world and type-approval, the many different driving modes available on PHEVs, all with different fuel and electrical demands, will indavetledly leave a gap between real world and type-approval figures for those customers whose driving and charging pattern do not fit the average. To empower customers to easily assess the fuel economy and CO2 emissions of a PHEV based on their own usage style, and to be able to assess whether a PHEV fits their needs, much more data on the real world performance of PHEV's needs to be made available at the point of sale than the information currently provided. This information should be based on data collected from OBFCM.

T&E recommends that the following information on PHEV labels:

1. **Fuel and electrical consumption as well as CO2 emissions in all driving modes.**
2. **Real world EV-only range**
3. **A clear explanation on the minimum share of driving which must occur in EV-only mode to achieve the type-approval fuel and electrical consumption and CO2 emissions.**

This data should be provided for that PHEV model**,** for new PHEV models for which OBFCM data may not yet be available, real world data should be modelled based on the similar vehicles on sale. The point of sale information should be updated with measured real world figures as soon as OBFCM data is available from a representative sample.

6.4. Fixing the WLTP test procedure

It is the WLTP test that ultimately influences the on-set design of the car and determines its CO2 and fuel performance before the car is placed on the market, i.e. before it is too late to change the car design. With many PHEVs entering the market, now is the time to update the rules to encourage carmakers to improve their actual design. It is therefore crucial that the European Commission - alongside its international partners in UNECE - without delay updates the PHEV WLTP procedure that was expected to be reviewed around 2020. This section outlines the key loopholes that should be closed.

6.4.1. Add the use of auxiliaries to the WLTP test

The use of auxiliaries, such as air conditioning, sat-nav or lights is not included in the WLTP test procedure. However their use has been reported to. increase fuel consumption[84] and therefore CO2 emissions, substantially. For PHEVs this happens in two ways:

- Firstly, by increasing CO2 emissions emitted by the car when the internal combustion engine is running due to an increase in engine load.
- Secondly, auxiliary use can decrease the EV range of the PHEV, due to their higher energy consumption. In some cases use of auxiliaries can also cause the ICE to come on early.

This dual effect is likely to have a bigger impact for PHEVs than for conventional ICE cars for which only the CO2 emissions are affected, meaning a bigger gap with real-world CO2 emissions and fuel consumption for PHEVs than conventional cars. In the U.S. one of the test cycles used for the type-approval of cars includes use of auxiliaries

Therefore, T&E recommends that the use of auxiliaries is introduced into the WLTP test procedure not only for PHEVs but all types of cars in order to increase the accuracy of all CO2 and fuel consumption figures.

6.4.2 Updating the definition of electric range

Secondly, at present there are at least 6 different ways to describe electric range of PHEVs:

1. All Electric Range (AER): The distance driven in charge depleting operation before the first start of the internal combustion engine.
2. All Electric Range (AER_{city}): The distance driven in charge depleting operation before the first start of the internal combustion engine, as tested on the WLTP city cycle, which comprises the low and medium speed phases only, essentially covering city driving.
3. Equivalent All Electric Range (EAER): The distance that could be driven by the use of the battery only, even if the ICE has already turned on. Essentially calculated by measuring the electrical distance driven until the HV battery is depleted and combining this with the electrical energy consumption measured during the AER. This is the distance that is made available to the consumer on the cars certificate of conformity.

[84] JRC. (2016) Review of in use factors affecting the fuel consumption and CO2 emissions of passenger cars.

4. Equivalent All Electric Range City ($EAER_{city}$): As above for EAER but determined on the WLTP city cycle.
5. Actual Charge Depleting Range (R_{CDA}): Is the distance driven before the HV battery is fully depleted.
6. Charge Depleting Cycle Range (R_{CDC}): Is the distance to the end of the WLTP cycle in which the battery becomes fully depleted. This is the distance used for the calculation of utility factors.

In reality this introduces a huge amount of complexity into the type-approval procedure of PHEVs and makes it difficult for third parties to establish the utility factors used at type-approval. For consumers, it introduces a huge amount of confusion as the EAER is not equivalent to the EV-only range that the PHEV can achieve, which is what matters when purchasing a PHEV. This can leave consumers feeling disappointed and cheated if the official values do not match what the car actually achieves on the road.

For simplification, T&E recommends that only the All Electric Range (AER), which is the actual distance that a PHEV can drive under EV-only operation, is used as a measure of electric range of PHEVs at type-approval as well as for inclusion in the vehicle's certificate of conformity (CoC).

6.4.3 Removing the K correction coefficient

Charge sustaining (CS, ICE-only) operation is defined in the WLTP regulation[85] as the operation of the PHEV vehicle where the state of charge (SoC) of the battery 'may fluctuate but the intent of the vehicle control system is to maintain, on average, the current state of charge'. In practice the SoC of the battery can increase during both the WLTP test and while driving on the road. The WLTP regulation introduced a new correction to account for any battery charging that may take place, the so called 'K correction coefficient' which essentially subtracts any CO2/fuel attributed to charging of the battery from the final result.

The problem with this approach is that this correction artificially reduces the CO2 emissions of the vehicle at type-approval and therefore provides artificially low CO2 values compared to what occurs on the road. For some PHEV vehicles increasing the SoC of the battery during CS operation can be a normal mode of operation. The X5 for example charged its battery by 5.94KWh during

[85] (EC) No 1151/2017.

the ICE-mode on-road test. So for this vehicle any CO_2 emissions emitted due to battery charging should be taken into account. This is especially important given the large increase in CO_2 emissions that was witnessed during this testing programme due to battery charging - in the end what matters for the climate is what is actually emitted during driving on the road, not on paper compliance **T&E recommends that the K correction coefficient is removed from the WLTP regulation in order to have more representative CO_2 values attributed to PHEVs.**

6.4.4 Increase the amount of data available on the PHEV's Certificate of Conformity

As already noted in section 5, there is next to no data available from manufacturers on the CO_2 emissions and fuel consumption of PHEVs in the different driving modes. This data is most notably missing from the car's certificate of conformity, which is a document which details the technical specifications and accompanies any car sale in Europe.

For the three cars tested, only a very limited amount of data was available from the car's certificate of conformity (CoC) in relation to the car's CO_2 emissions, notably the charge sustaining NEDC and WLTP CO_2 emissions. For the XC60 only, the car's WLTP CO_2 emissions in charge sustaining mode were provided. Discouragingly, the BMW's and Outlander's CoC's failed to provide WLTP CO_2 emissions or fuel consumption in charge sustaining mode, which are needed to provide information on how the car performs when driving using only the internal combustion engine. For use in this testing programme the data had to be obtained from the manufacturers directly, which can take a long time and be problematic. Despite Emissions Analytics requesting this data for the Outlander, it was not provided by Mitsubishi.

Inclusion of this data on the CoC is mandatory for conventional vehicles but it appears not to be included for most PHEVs. However, this data is crucial for third parties for compliance verification as well as for consumers to know and understand the approximate CO_2 emissions and fuel consumption of these PHEVs when the battery is not charged.

T&E therefore requests that the Commission clarifies the reporting requirements for PHEVs and aligns these with the requirements for conventional cars, to ensure that charge sustaining CO_2 emissions as well as fuel consumption are included in the PHEV's Certificate of Conformity.

6.5 Subsidies for PHEVs

T&E commissioned Schmidt Automotive Research (Methodology Annex 4) to calculate how much public money will go into subsidising private and corporate PHEVs in Germany, France, Italy, Spain and the UK in 2020 (table 5). In total from January to September these five Member States alone are estimated to spend in excess of €436 million on PHEV purchase subsidies. During the entire year another €555 million is expected to be lost from foregone tax revenue due to lower rates of benefit in kind tax applied to company PHEVs. In total these five Member States are expected to spend in excess of 1 billion euros subsidising PHEVs in 2020.

In Germany between June-September, the BMW X5 (which BMW deliberately prices at €50 below the PHEV purchase subsidy threshold) received in excess of €4 million in taxpayer subsidies. This is despite likely failing to deliver the expected CO_2 savings on the road as described in section 5.2.

	Purchase subsidy Jan-Sep 2020 (EUR)	Reduced benefit in kind tax 2020 (EUR)
🇫🇷	38,278,000	7,262,640
🇩🇪	348,310,500	208,353,600
🇮🇹	27,999,500	N.A
🇪🇸	21,494,700	N.A
🇬🇧	N.A	339,068,984
Total	436,082,700	554,685,224

Source: Schmidt Automotive Research

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Table 5. Estimated subsidy spend on PHEVs in France, Germany, Italy, Spain and the UK in 2020. Purchase subsidies are calculated based on actual vehicles sold in each country between January to September 2020. Reduced benefit in kind tax income is estimated based on the top 5 selling models in Western Europe Jan-Sep. 2020 (Mitsubishi Outlander, Ford Kuga, Volvo XC60, VW Passat, Volvo XC60). Scrappage scheme subsidies are not taken into account.

6.5.1 Subsidies for company PHEVs

In 2019, sales of PHEVs in the EU were dominated by company car purchases, accounting for 72% [86] of PHEV sales and totalling 133,060 units.[87] Company car PHEVs are subject to particularly generous purchase incentives across many Member States (Figures 2 and 26), delivered through purchase tax, road tax, company car tax and depreciation incentives. This ranges, on average, from €800 euro in the UK up to over €10,000 in Norway.

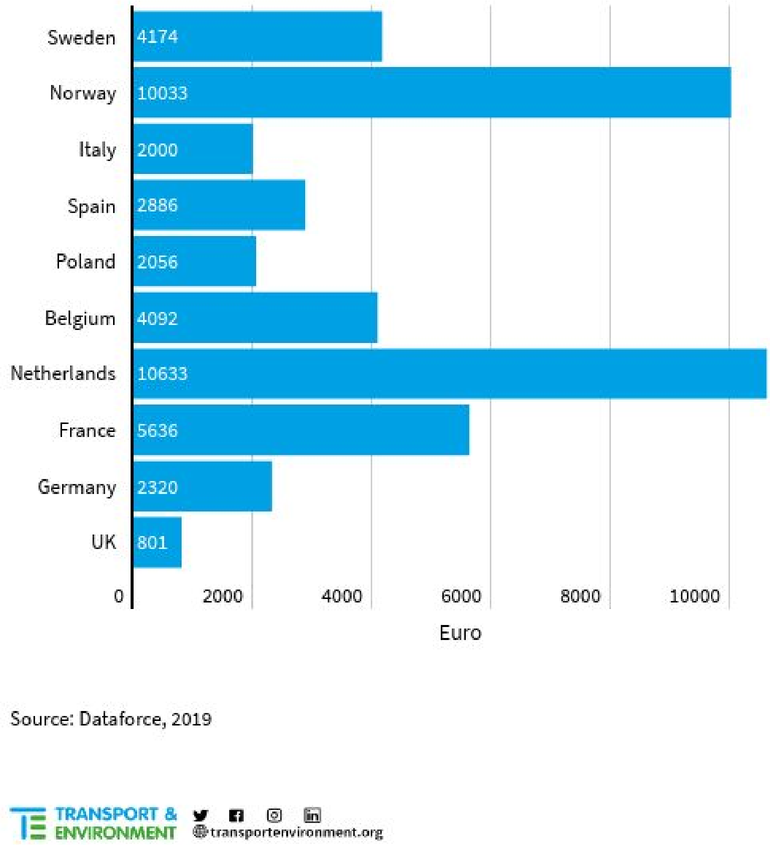

Figure 25: Average incentives for corporate PHEVs in key EU countries[88] . Source Datforce.

[86] Dataforce on behalf of T&E. Dateforce. (2020) Transport Environment: company car report.
[87] T&E. (2020) Company cars: how European governments are subsidising pollution and climate change.
[88] As compiled by Dataforce on behalf of T&E. Dateforce. (2020) Transport Environment: company car report.

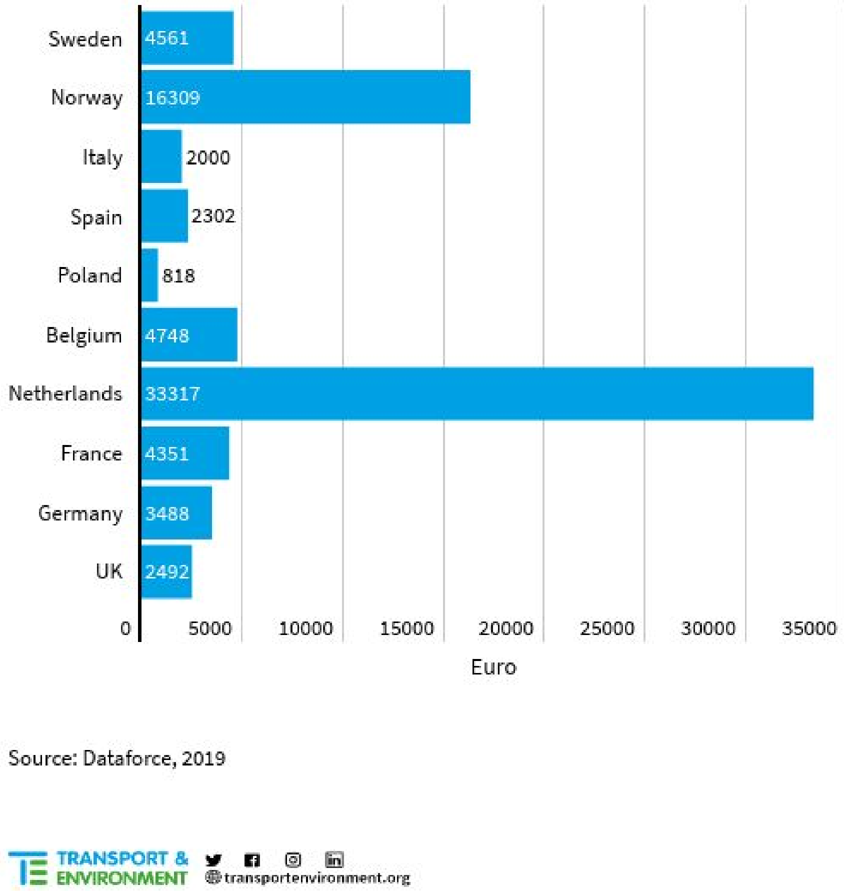

Figure 26: Average tax benefit of purchasing a corporate medium PHEV SUV compared to a medium diesel SUV

Despiter company PHEVs, real world usage data from Germany and the Netherlands[89] shows they are barely driven under electric operation. The real world UF of corporate PHEVs is about a third of what is assumed by the regulation, resulting in these cars having much higher CO2 emissions

[89] Table 1 in Section 4.1.3, source ICCT. (2020) Real-world usage of plug-in hybrid electric vehicles: Fuel consumption, electric driving and CO2 emissions.

and fuel consumption in the real world and meaning that the climate benefit of corporate PHEVs, in practice, is very limited.

Part of the issue is that while these vehicles are subject to generous purchase incentives, there are next to no incentives or policies in place to encourage corporate PHEV owners to drive the cars mainly under EV operation. A DataForce survey of 58 fleet managers in Germany, whose fleets contain PHEVs, revealed that only 5% of them currently have policies in place on how much driving needs to occur in EV-mode. Interviews with managers of ten large European fleets reveal that no such policies currently exist in their fleet and there is no clear roadmap for putting measures in place to monitor PHEV usage.[90]

Corporate PHEV owners may also be discouraged from charging if refueling is cheaper or access to charging infrastructure is limited. Many owners of company cars in the Netherlands and Germany receive fuel cards which allow for free refuelling; but if recharging at home, corporate PHEV users may be expected to pay for the additional electricity consumed. This may encourage PHEV drivers to use the engine and not charge their PHEVs. Even if in some countries home charging is tax deductible, this may not be enough to encourage charging over fuel use. Additionally, PHEV owners may not have access to work or home charging at all, making recharging a PHEV less convenient than re-fuelling. This is particularly a problem for PHEVs on sale today which largely have a short electric range and where at least daily charging may be necessary for them to achieve high utility factors.

While it appears that privately-owned PHEVs are charged more often, their CO2 emissions and EV mode operation is still well below what the official values assume. Similarly to corporate PHEVs, these vehicles should only be incentivised if they achieve the low emission benefits advertised.

The power to influence what low emission cars are purchased and how these are used rests largely with the Member States. The first issue to fix is taxation policy. First, they should not be subject to the same purchase and tax incentives as zero emission cars, e.g. battery electric. **PHEV incentives should be based on the electric range of the vehicle and be capped at a maximum of half the incentives given to ZEVs. In order to encourage the purchase of PHEVs which are more likely to deliver substantial CO2 and fuel savings, incentives should also be limited to**

[90] Dataforce on behalf of T&E. Dateforce. (2020) Transport Environment: company car report.

PHEVs with a minimum range in EV-only mode of at least 80 km, based on the WLTP all electric range. For corporate fleets, PHEVs should get no incentives, be it through tax breaks like VAT deductions or depreciation write-offs, or through beneficial BIK (Benefit-In-Kind) rates, unless they can be driven in EV-only mode for at least 80 km. Once OBFCM data is available, the 80km range should be based on real world EV-only range in order to ensure that the cars are capable of achieving that range under real world conditions.

Germany has already done so with a required EV range of 60km between 2022-2024, increasing to 80km from 2025-2030. However, while Germany allows cars with less than the required range to qualify if their CO2 emissions are less than 50g/km, which, for example, would qualify the Outlander despite not meeting the minimum EV- range requirements, Member States should ensure that PHEVs are required to meet both EV-range and maximum CO2 requirements.

However, the problem cannot be solved by increasing the EV-only range of the car alone. **PHEV subsidies should be limited to companies where access to sufficient workplace charging is available. No fuel card should be provided, instead an electric charging card can be provided to help facilitate charging on the go.** This would be especially useful for those company PHEVs which undertake longer journeys, away from the workplace, where regular charging on the go could help increase the share of electric kilometers driven. **For private owners - access to regular charging should equally be demonstrated to benefit from incentives.**

Fleet operators also have a part to play in greening up the PHEV fleet by more actively managing vehicle choice and usage behaviour. They should advise those consumers who regularly drive long distances that a PHEV is likely not a suitable car option for them as they will not be able to achieve the fuel and CO2 savings advertised. Workplace education campaigns and benefits for regularly charging PHEVs could also be helpful in encouraging charging behaviour.

6.6 Summary

In summary, the information presented in this report shows that PHEVs fail to achieve the advertised CO2 emission and fuel economy savings advertised in the real world. This allows manufacturers to unjustly benefit from low CO2 emissions of these vehicles, making it easier for them to meet their fleetwide CO2 targets. Consequently, undermining the 2020/21 CO2 regulation and reducing the number of real zero emissions cars that need to be sold. If PHEVs are to aid the transition to zero-emission mobility in the 2020's, urgent changes to EU laws - notably around testing and CO2 credits in vehicle standards - are necessary to make sure that PHEVs supplied on the EU market are not just 'compliance vehicles'. Official CO2 and fuel consumption figures have to reflect the actual usage of these cars in the real world. Manufacturer's also have to make better PHEVs which are capable of driving much longer distances under electric only operation, under all conditions of use. To further encourage demand for better PHEVs, Member States should reform purchase and tax incentives to ensure that only long range PHEVs can benefit. It is especially important to reform company car incentives given that these make up more than three quarters of PHEV sales today.

7. Annexes

Annex 1: Specification of the three PHEVs tested

PHEV Specification

	BMW X5	Volvo XC60	Mitsubishi Outlander
Derivative	XDrive45E M PHEV	R Design Pro T8 PHEV	5H PHEV
Type-approval	WLTP 6d-temp ISC	WLTP 6d-temp	WLTP 6d-temp
Registration year	2019	2018	2019
Mileage at start of testing	3,972	16,512	32,672
Fuel	Petrol	Petrol	Petrol
Engine size	3.0L	2.0L	2.4L
Power (bhp)	394	384	206
Drivetrain	AWD	AWD	AWD
Battery size (kW)	24.0	10.4	13.8
Charger	2.3kW/3.7kW	2.3kW/3.7kW	2.3kW/3.7kW/CHAdeMO (50kW)
Electric motor max net power (kW)	83	10+6	130
Electric motor max hourly output (kW)	55	65+52	55

Source: Vehicle's certificate of conformity and Emissions Analytics

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Annex 2: Characteristics of on-road test routes

Test routes

	RDE compliant	Dynamic/Elevation	Reverse Order
Trip distance (km)	92	100	100
Urban distance (km)	36	44	23
Average urban speed (km/h)	32	35	34
Rural distance (km)	29	26	26
Average rural speed (km/h)	73	72	74
Motorway distance (km)	27	30	51
Average motorway speed (km/h)	105	105	107
Average altitude (m)	110	149	132
Cumulative positive elevation gain (m/100km)	544	1276	703
Relative Positive Acceleration (m/s^2)	0.14	0.2	0.11
V*Apos@ 95th Percentile (m^2/s^2)	14.77	26.68	15.58

Values are an average of all tests undertaken on each route.

Source: Emissions Analytics

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Annex 3: Further methodology: Calculation of fleet average CO2 emissions

T&E's modelling of fleet average CO2 emissions of BMW and Volvo described in this report follows the methodology described in T&E. (2020) Mission (almost) accomplished and is based on EU car registration data obtained by T&E from JATO Dynamic for the first half of 2020.

T&E used PHEV NEDC charge sustaining emissions obtained from the EV-database [91] (www.ev-database.uk) for calculating PHEV combined NEDC values (based on utility factors of 20-70%) for use in the modelling detailed in this report. These values were used because, unfortunately, manufacturer's do not make NEDC charge sustaining emissions of PHEVs publicly available so official values cannot be used. Also, since the CO2 type-approval of passenger cars switched from the New European Drive Cycle (NEDC) to the World Light-duty Test procedure (WLTP), manufacturers do not publish the NEDC electric range or combined NEDC CO2 emissions of PHEVs type-approved under the WLTP procedure. This is a problem as they are both necessary for calculating an estimate of the NEDC charge sustaining emissions of PHEV vehicles. It should be noted that for some vehicles the NEDC CO2 emissions values obtained from the EV-database may be estimated based on WLTP type-approval values.

For two vehicle models for which charge sustaining emissions were unavailable from the EV-database: the BMW 530e M Sport Touring and BMW 530e xDrive M Sport Touring models T&E estimated the charge sustaining emissions by calculating the gap between Series 3 saloon and Series 3 touring models's charge sustaining emissions (for both standard and xdrive models) and adding the gap to series 5 saloon models (standard and xDrive). For the BMW i3, official NEDC CO2 emissions values were used (and not altered depending on the utility factor) due to the very small petrol tank fitted to this vehicle, making it unlikely that a large share of kilometers would be driven using the internal combustion engine by this PHEV.

Sales shares of individual models and their variants were estimated based on combined NEDC emissions obtained from Jato Dynamics. Where this was not feasible, the sales share of model variants were assumed to be split equally (e.g. 25%/25%/25%/25% split for sales of BMW series 3 models: 330e M sport touring Saloon, 330e xDrive SE Pro Saloon, 330e M Sport Saloon, 330e xDrive M sport Pro edition Touring). Charge sustaining emissions used for each model are shown in the table below.

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[91] EV database calculates charge sustaining emissions using the following equation: combined NEDC CO2 x (NEDC electric range + 25))/25. 25 is the average distance drive in charge sustaining mode as assumed by UN-ECE R101. EV-database assumes that the CO2 emissions in charge depleting operation are 0.

The full year compliance of both OEMs was assessed based on T&E's existing model and expected compliance pathway per carmaker. Six different OEM average PHEV combined NEDC values were calculated based on six different utility factors (from 20% to 70%, with a 10% step increase). By replacing the PHEV average emissions with the new adjusted value, the OEM's fleet average CO2 was established by the model. Importantly, from a 60% utility factor and below, both BMW and Volvo do not earn super-credits any longer as all PHEVs sold would have CO2 emissions above 50 g/km .

BMW	Charge sustaining CO2 (g/km)
SERIES 3	149
X5	195
X3	157
SERIES 5	149
SERIES 2 ACTIVE TOURER	146
X1	146
SERIES 7	168
I8	143
Volvo	
XC60	138
XC40	134
V60	127
XC90	148
V90	139
S60	127
S90	139

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Annex 4: Calculation of PHEV subsidies by Schmidt Automotive Research

Purchase subsidies in each market (France, Germany, UK, Italy and Spain) were calculated based on the actual sales volume of each PHEV sold in the respective market between January to September 2020. Various changes made post pandemic were taken into account

Loss of benefit-in-kind (BiK) tax revenue in each market (France, Germany, UK, Italy and Spain) were calculated for the entirety of 2020 and based on the top 5 registered PHEV models(Mitsubishi Outlander, Ford Kuga, Volvo XC40 and X60, VW Passat) in Western Europe (18 markets) from the European Electric Car Q3 report, which together accounted for 25% of the total market in the opening 9 months of the year. For these models the mean values for; price (German prices), EV range (KM plus UK miles), CO2 emissions and mean CO2 emissions of the entry petrol models were used as a basis to work out the reduction in BiK revenue from the PHEV fiscal savings. Scrappage scheme subsidies are not taken into account.

The BiK savings are based on a 12-month period i.e the entirety of 2020, whereas purchase subsidies are calculated for the opening 9-months of the year.